SEDIMENT DYNAMICS OF AN IMPOUNDED RIVER:

YEGUA CREEK, TEXAS

A Thesis

by

ADRIANA E. MARTINEZ

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2008

Major Subject: Geography

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Approved by:

Chair of Committee,	Anne Chin
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ABSTRACT

Sediment Dynamics of an Impounded River:

Yegua Creek, Texas. (May 2008)

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Chair of Advisory Committee: Dr. Anne Chin

Dams have altered flow distributions in rivers everywhere, causing a host of changes in channel morphology and sediment dynamics. Although major changes in flow regime have occurred along Yegua Creek, Texas, since the closure of Somerville Dam in 1967, the issue of sediment transport has not been studied in detail. The extent to which sediment is moving through the system remains unclear. This study addresses the extent to which sediment is moving through and downstream of the dam. Analysis of sediment samples collected at 23 sites in the Yegua Creek channel system showed that coarse sand to silt-sized materials dominate the creek upstream of the dam, whereas finer silt and clay sediments characterize the downstream portions. Calculation of the trapping efficiency of the dam indicates that approximately 99.8% of materials from the upper watershed are trapped behind Somerville Dam. Investigations of sediment mobility further suggest that present flows are capable of mobilizing sediments downstream of the dam. Although a de-coupling between the upper and lower portions of the Yegua Creek watershed has likely occurred due to the high rate of sediment trapping, new sediment sources that include tributaries and alluvial storage likely play a larger role in providing materials for sediment transport downstream. Despite a reuction

in peak flows, the channel morphology of Yegua Creek has apparently adjusted over the four decades since construction of Somerville Dam to achieve a new equilibrium characterized by sediment movement. These results are corroborated by analysis of aerial photographs.

These findings augment our understanding of the many facets of the response of fluvial systems to the disturbance posed by dam construction. Because Yegua Creek is a major tributary to the Brazos River draining to the Texas coast, increased understanding of sediment dynamics within Yegua Creek provides critical insights into the efficacy of sediment delivery in a regional context, and ultimately to the Texas coastline. The findings of this study also provide useful information for managing stream ecosystems affected by impoundments.

DEDICATION

To my parents, Juanita and Cesar Martinez,
my sister, Alejandra Martinez and
my grandmother, Olivia Rodriguez

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CHAPTER I

INTRODUCTION

Background

Dams have changed rivers everywhere. They have altered flow distributions and sediment transport, causing a host of adjustments in channel morphology and sediment dynamics. Although major changes in flow regime have occurred along Yegua Creek, Texas, since the closure of Somerville Dam in 1967, sediment transport changes have not been studied in detail. The extent to which sediment is moving through the system remains unclear. Because Yegua Creek is a principal tributary to the Brazos River and an important source of water supply in the south-central region of Texas, increased understanding of sediment dynamics within Yegua Creek is especially important. This study evaluates the extent to which the present flow regime is transporting sediment through Somerville Dam and downstream of the dam. Sediment characteristics are examined in the laboratory and with theoretical calculations. First, the characteristics of the trapping efficiency will test the hypothesis that little sediment is passing through the dam. Second, sediment characteristics and their capability of transport will be examined to test the hypothesis that flows are mobilizing sediment downstream of the dam. Aerial photographic observations further evaluate the extent to which immobile sediments form depositional features downstream of the dam. Results give insight into some of the consequences of stream impoundment. They also increase our understanding of the

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This thesis follows the style of Geomorphology.

efficacy of sediment delivery into the Brazos River and ultimately to the Texas coastline.

Objectives

This project extends previous studies of the effects of Somerville Dam on Yegua Creek, Texas. Yegua Creek is a principle tributary to the Brazos River and an important water supply for the Brazos River Authority, the largest water rights holder in the region. Previous research has documented dramatic changes in the flow regime and channel morphology of Yegua Creek following closure of Somerville Dam in 1967 (Chin et al., 2002; Chin and Bowman, 2005). Flow regulation has created a more equitable flow regime due to a reduction in flood peaks (85%) and an increase in low flows (Chin and Bowman, 2005). Furthermore, as a result of the reduction in peak flows, the channel system has adjusted so that a 65% decrease in channel capacity (largely due to a 61% decrease in channel depth) was found downstream of Somerville Dam by 2002 (Chin et al., 2002). Although such changes are expected to induce, and perhaps result from, changes in sediment movement through the river system, the sediment dynamics of Yegua Creek have not been investigated in detail. A paucity of research has addressed the effects of dams on Texas rivers in general (Chin et al., 2008), even though more than 7000 dams have been constructed in the state (Graf, 1999). This research is significant because it provides insight into the efficacy of sediment delivery within a major dammed river system to the Texas coastline. It also contributes to an increased understanding of the impact of stream impoundment on river systems as a whole (Graf, 2006). This knowledge in turn aids in determining sustainable management practices (e.g. Downs and Gregory, 2004)

This study addresses two specific research questions. First, to what extent is sediment moving through Somerville Dam? The working hypothesis is that insignificant quantities of sediment passes through the dam because of sediment trapping by the dam. This effect potentially disconnects the upper and lower watersheds and starves the downstream portion of sediments that were delivered from the upstream basin before impoundment. This hypothesis was developed based on studies of similar river systems where impoundments have trapped large amounts of sediment behind the dam. For example, 98% and 90% of the sediment load is deposited behind the High Aswan Dam on the Nile River (Hammad, 1972) and Toledo bend reservoir along the Sabine River, Texas, respectively (Phillips, 2003). Additionally, sediment starvation below Lake Livingston has resulted in a similar "decoupling effect" of sediment on the Trinity River, Texas (Phillips et al., 2004).

The second research question addressed in this thesis is: to what extent are present flows capable of transporting sediment downstream of Somerville Dam? The working hypothesis is that the reduction in flood peaks associated with river regulation has decreased sediment transport capacity in Yegua Creek. This reduction in transport capacity would decrease significantly the quantity and size of sediment moving into the Brazos River. The hypothesis for the second objective was developed based on previous studies elsewhere that showed that a reduction in sediment transport. For example, in the nearby Trinity River, a reduction in sediment transport was documented to result from accompanying decreased flows (Phillips 2003). In the case of Yegua Creek, peak discharges have also been reduced as a result of flow regulation (Chin et al. 2002). Sediment transport capacity is expected to have decreased as well. Furthermore, initial review of aerial photographs and reconnaissance surveys showed a growth of sand bars in the reaches downstream of Somerville Dam, suggesting that depositional processes may have taken place. This hypothesis is also consistent with the previous finding that channel capacity has decreased in size since construction of the dam (Chin et al., 2002).

Organization of the Research

This thesis consists of six chapters. Chapter I is an introduction that is followed by a literature review in Chapter II outlining the effect of dams on the hydrological, sedimentological, morphological, and ecological characteristics of streams. Chapter III describes the study area and includes climate, vegetation, and geology. This chapter also summarizes previous research pertaining to the effects of Somerville Dam on Yegua Creek. Chapter IV outlines the field and laboratory methods, as well as theoretical calculations and aerial photograph analysis methods used to answer the research questions. Chapter V presents the results, followed by a discussion of the findings, conclusions and avenues for future research in the final chapter (Chapter VI).

CHAPTER II

LITERATURE REVIEW

Introduction

Several groups of studies form the theoretical background for this research. The first summarizes hydrological effects occurring downstream of impoundments. Sedimentological effects comprise the second theme and include changes in basin sediment budgets, sediment yield, bed and suspended sediment loads, and the distribution of sediment sizes along the stream. The third group includes changes in channel morphology associated with dam construction. A fourth group addresses ecological effects of stream impoundment. These include altered species biodiversity, distribution, colonization, and the ability of ecosystems to support a species population after impoundment.

Hydrological Impacts

Each dam uniquely changes the flow characteristics of the impounded stream according to its main purpose and local geography. For example, dams used primarily for irrigation do not release water during some periods the year or concentrate their releases during the growing season (Williams and Wolman, 1984; Elliot and Parker, 1997; Jennings, 1999). In contrast, hydroelectric dams that generate power release water in pulses (Ibanez et al., 1996; Magilligan and Nislow, 2001; Phillips, 2003). Therefore, flows can be redistributed throughout the year, resulting in more or less variable flow, depending on the individual dam (Ibanez et al., 1996; Jennings, 1999; Chin et al., 2002; Yang et al., 2004; Chin and Bowman, 2005).

Although the purpose and effects of dams may differ greatly, studies have shown some consistent trends. Typically, peak discharges have decreased after impoundment (e.g. Williams, 1978; Graf, 1980; Chin et al., 2002; Chin and Bowman, 2005; Singer, 2007). In one example, Andrews (1986) found that on the Green River in Utah below Flaming Gorge Reservoir, discharges equal to, or exceeding 5,000 ft^3/s that occurred 10% of the time prior to impoundment no longer occurred after impoundment. Elsewhere, the recurrence intervals of peak discharges along the Milk River, Alberta, and Montana, increased 2-3 times their pre-impoundment recurrence interval, meaning that large events became rarer (Bradley and Smith, 1984). Along Yegua Creek, the site of interest for this study, Chin and Bowman (2005) established that a more equitable flow regime developed downstream of Somerville Dam. The post-dam flow regime reflects an 84% decrease in annual peaks.

Impoundment also affects the frequency and magnitude of floods. Frequencies of specific floods, especially high magnitude events, often decrease following impoundment (Bradley and Smith, 1984; Graf, 1988; Higgs and Petts, 1988; Shields et al., 2000; Magilligan et al., 2003; Chin and Bowman, 2005). In some cases, however, such as when dams overspill and induce rare peak discharges, high and low flow extremes may not be as affected. The River Mersey in Tasmania exhibited such characteristics (Knighton, 1988a).

In addition, average flows (specifically mean annual and mean daily flows) are altered on many streams after impoundment (e.g. Williams and Wolman, 1984; Surian, 1999; Maigini and Marsh, 2002; Chin and Bowman, 2005). Along the River Severn (U.K.), Higgs and Petts (1988) found a 50% and 30% decrease in median and mean annual flows, respectively. In addition, the mean annual discharge decreased 28% on the Green River, Utah (Allred and Schmidt, 1999). This may be due to the intended uses for the stored water which influence the timing and quantity of releases.

Sedimentological Effects

Decreased discharges from dams can result in decreased transport capacities along impounded rivers. For sediment transport, stream power, not water quantity, is the important variable to consider (Knighton, 1987). For this reason, sediment load (or sediment transported below the dam) is often altered after stream impoundment owing to a reduction in stream power (Chien, 1985; Graf, 1988). For example, Allred (1999) recorded a decrease in the magnitude of discharge responsible for transporting the majority of suspended sediment along the Green River in Utah. Therefore, suspended sediment was less likely to be transported following impoundment. On the Green River, Graf (1980) also found that 93% of the boulders stabilized after impoundment compared to 62% before dam closure because of decreased transport capacities of the flow. These decreases in entrainment capabilities may ultimately affect sediment supply to coastlines, and therefore beach erosion (Chin et al., 2002).

Dams can cause coarsening of sediment downstream because, with decreased entrainment, only fine sediments are carried away (Graf, 1980; Chien, 1985). Bed materials also coarsen because of the clear water or “hungry water” effect (Kondolf, 1997), whereby sediment-free water erodes channels until a new equilibrium is reached. This process leads to higher bed roughness values as the hungry water removes finer sediment, leaving behind coarser particles. As a result, this roughness decreases the flow velocity in the channel and ultimately, decreases stream power (Hammad, 1972; Kellerhals, 1982; Knighton, 1987; Graf, 1988; Graf, 2005). Such was the case on the River Rheidol, U.K., (Greenwood et al., 1999), Bear Creek, Colorado (Hadley and Emmett, 1998), and the Nile River below the High Aswan Dam (Kashef, 1981). Sediment coarsening eventually can lead to armoring along channel beds (Richards, 1982; Magilligan et al., 2003; Graf, 2005). As a result of sediment-free water released from the impoundment, for example, armoring occurred below the Elwha Dams in Washington (Pohl, 2004). These effects can diminish with increasing distance from the dam, as well as with time (Williams and Wolman, 1984).

Dams can also cause changes in particle size distributions downstream. The Colorado River, for example, had a uniform sediment size distribution downstream of the impoundment before the closure of Hoover Dam. Six years after impoundment, sediments downstream of the dam became sorted, so that a greater portion of coarser particles were present immediately below the dam. Median particle size gradually decreased with distance from the dam. This is likely due to the decrease in peak flows no longer able to transport coarser material. Instead, flows present after impoundment transport fine sediment present, leaving behind coarser material (Williams and Wolman, 1984).

Sediment budgets describing sediment input, output, transport and storage are useful indicators of change after impoundment (Reid and Dunne, 2003). Using sediment budgets, Andrews (1986) showed that equilibrium was present in the suspended sediment characteristics along the Green River in Colorado and Utah prior to impoundment. However, the mean annual sediment discharge since dam closure has decreased significantly. Therefore, the amount of sediment transported into the river reaches is currently much higher than sediment transported out of river reaches along the Green River (Andrews, 1986). The sediment budget approach also allowed Phillips et al. (2004) to conclude that changes in sediment input, output, transport and storage due to impoundment on the Trinity River, Texas, did not affect sediment delivery to the coast. Although Livingston Dam trapped 81% of sediment entering the dam, the lower portion of the basin supplied much of the sediment supply to the coast.

The sediment trapping efficiency of a reservoir provides a useful parameter to determine the sedimentological impacts of a dam (Williams and Wolman, 1984). A reservoir can trap large amounts of bed and suspended sediment, disconnecting the upstream portion. Often, the upper basin can provide greater than 75% of the sediment load to the lower basin (Petts and Gurnell, 2005), from the downstream basin (Bonacci et al., 1992; Phillips, 2003; Petts and Gurnell, 2005). For example, approximately 90% of the suspended sediment load is deposited behind Toledo Bend Reservoir on the Sabine River (Phillips, 2003). At a global scale, reservoirs trap approximately 30% of the sediment flux (Vorosmarty et al., 1997; Vorosmarty et al., 2003). These changes can significantly impact sediment supply to stream reaches downstream, and eventually, to coastlines.

Tributaries and other downstream sediment sources can offset the effects of impoundment (Knighton, 1987). Carling (1988) found that tributaries supplied fine sediments along many U.K. Rivers. Tributaries also supplied a large amount of sediment on the Gunnison River, Colorado (Elliot and Parker, 1997), the River Mersey in Tasmania (Knighton, 1988a), and the Green River, Utah (Grams and Schmidt, 2005). Often, the regulated discharge is unable to entrain a large amount of sediment supplied by tributaries (Kondolf, 1997). Thus, the River Chew in Somerset changed from a primarily gravel bed river to sand bed because of tributary inputs following impoundment (Petts and Thoms, 1986).

Morphological Changes

Changes in flow and sediment characteristics caused by dams can induce a variety of morphological effects downstream (Richards, 1982; Williams and Wolman, 1984; Brandt, 2000). Changes in slope may occur below impoundments as a result of the inability of the new flow regime to entrain sediment (Chien, 1985; Brandt, 2000). Changes in sediment size distribution caused a steeper slope to develop on the River Rheidol, U.K. (Greenwood et al., 1999).

Channel widths commonly adjust after stream impoundment because of changes in discharge and sediment transport (Williams and Wolman, 1984). Channel widening is the most common response; it was reported for 46% of the 231 cross sections in the classic study by Williams and Wolman (1984). Specifically, along the River Ter (UK), channel capacity increased at three sites directly below the dam due to channel scouring (Petts and Pratts, 1983). Conversely, channels with no change in width were found in 22% of the channels studied by Williams and Wolman (1984). In addition, 26% of the channels narrowed (Williams and Wolman, 1984). Channel width narrowed by an average of 10-13% after impoundment along the Green River, Utah due to decreased effective discharge (Andrews, 1986; Allred and Schmidt, 1999; Grams and Schmidt, 2005). Five percent of the 231 cross sections studied by Williams and Wolman widened and then narrowed, whereas 2% narrowed and then widened (1984). One example of such an occurrence is the Green River in which Merritt and Cooper (2000) found that after impoundment the stream first narrowed by 13% and later widened by 20%.

One study along the Missouri River explains morphological channel changes as a result of bank composition and cohesiveness. One reach consisting of sand and a high silt content experienced more erosion and undercutting at low flows compared to other reaches along the same river. However, areas with silt-clay blocks prevented erosion for some time. Therefore, cohesive banks are likely to deter channel width increases (Rahn, 1977; Williams and Wolman, 1984).

Changes in flow regime and sediment characteristics can also cause changes in channel planform. Braiding commonly develops in areas of increased flow, whereas meandering tends to occur in cases with decreased flow (Williams, 1978; Graf, 1988; Brandt, 2000; Wellmeyer et al., 2005). The Piave River in Italy, for example, became less braided after impoundment (Surian, 1999). In addition, meander rates decreased downstream of an impoundment as a result of a reduction in flow and sediment transport capacities. Along the Milk River in Alberta and Montana, meander rates downstream of the impoundment were found to be much lower compared to those occurring upstream (Bradley and Smith, 1984). The Snake River below Jackson Lake Dam in Wyoming also became more sinuous, increasing meander rates. Channels actively migrated downstream of tributaries that provided adequate sediment supplies and effective discharge (Marston et al., 2005).

River bed changes have also been reported after stream impoundment (Brandt, 2000). Degradation below impoundments (Graf, 2001) was documented in all 21 cross sections outlined in Williams and Wolman (1984). Degradation can switch to aggradation some time after dam closure or at some distance downstream of the impoundment (Wolman, 1967; Chien, 1985). In one dramatic example, the Skokomish River in Washington, impounded in the late 1920s, experienced incision between 1932 and 1938. The river then aggraded from 1939 to 1944. Later, between 1964 to 1997 the channel began to aggrade rapidly (Stover and Montgomery, 2001). Thus, channel adjustments vary greatly from river to river.

Ecological Impacts

Changes in channel form and flow and sediment characteristics associated with stream impoundments may ultimately affect stream ecosystems and the ability of streams to support organisms (Ligon et al., 1995; Magilligan et al., 2003). Adjustments in channel shape can influence vegetation establishment by providing open areas for vegetation to flourish (e.g. Bradley and Smith, 1984; Williams and Wolman, 1984; Carling, 1988; Elliot and Parker, 1997; Fergus, 1997; Greenwood et al., 1999; Marston et al., 2005; Petts and Gurnell, 2005). In Yegua Creek (Texas), a 25% increase in riparian woodland was noted between 1958 and 1980 (Jennings, 1999). In addition, 90% of the active bars on the Green River near Browns Park had been populated by vegetation only 10 years after impoundment (Merritt and Cooper, 2000).

Stream impoundment can alter vegetation biodiversity downstream of the dam. Along the Snake River, Wyoming, Marston et al. (2005) discovered that unstable parts of the channel increased in biodiversity, whereas biodiversity decreased on the stable sections between 1945 and 1989. Unstable channel reaches prove difficult to colonize and therefore give a wider variety of new species a chance to colonize the area. On the other hand, stable reaches allow developed species to flourish. The proliferation of these developed species, therefore, do not allow the colonization of new species (Marston et al., 2005). Furthermore, channel scouring below a dam can create fewer opportunities for seedlings to germinate. This can lead to a decrease vegetation growth, thus decreasing vegetation biodiversity (Williams and Wolman, 1984).

Water quality, and specifically water chemistry, can change as a result of impoundment. Often, this is due to changes in the chemical and biological processes taking place within the reservoir (Pozo et al., 1997). These changes are translated to the water released into the stream. Any changes in water quality affect the life cycles of organisms (Graf, 1980; Magilligan and Nislow, 2005). Along the River Rheidol, U.K., macroinvertebrates were affected due to changing flows and siltation. An increase in the number of taxa in reaches that were regulated and still adjusting in channel change was apparent (Greenwood et al., 1999). In another study, Petts (1986) emphasized the possibility of eutrophication if adequate flows are not available to flush away nutrients.

The Context for Yegua Creek

The effects of stream impoundment are gradually being uncovered as more research is conducted on the hydrological, morphological, sedimentological, and ecological impacts of impoundment. Along Yegua Creek, Texas, the impoundment of Somerville dam has resulted in an 85% decrease in peak flows and a more equitable flow regime (Chin and Bowman, 2005). This decrease in peak flows and increase in low flows is common among streams after impoundment. These changes in flow regime are accompanied by a reduction in channel capacities, after several decades, averaging 65%. The changes in channel morphology occurred principally due to depth reductions, whereas no significant changes in channel width were found (Chin et al., 2002). This decrease in channel capacity, and specifically changes in depth, has been attributed to decreased flows in similar studies along the Rio Grande (New Mexico) and the Peace River, Canada (Williams and Wolman, 1984). These decreased flows no longer have the ability to entrain available sediment and therefore, the sediment remains in the channel. In addition, an increase in riparian vegetation was found likely due to the decrease in peak flows that no longer have the ability to disturb vegetation establishment (Jennings 1999).

The background provided by previous investigations of Yegua Creek presents a unique opportunity to add insight into the overall response of river systems to dam construction. Having documented the hydrological and morphological changes (Chin and Bowman, 2005, Chin et al., 2002), what, if any, are the sedimentological responses? Is sediment moving through the dam and downstream of the dam? In light of the reduction in peak flows, has sediment transport been altered such that the presence, number, and size of depositional features along Yegua Creek have grown? What are the possible roles of tributary inputs of sediments? Has sediment coarsening accompanied other changes? Understanding the sedimentological effects will ultimately provide insights toward linking the responses in system components. An integrated understanding of system response for Yegua Creek is expected to add significantly to our knowledge of the impacts of dams in general.

Increased understanding of sedimentological effects of Somerville Dam on Yegua Creek is also important in a regional context. Because Yegua Creek is a major tributary to the Brazos River, changes in sedimentological processes will ultimately affect sediment delivery to the coast. Phillips et al. (2004) have documented sedimentological changes on the Trinity River, approximately 100 km east of the Brazos River. The authors reported that alluvial storage downstream of Livingston Dam is such that little change has occurred in sediment supply to the Texas coast. Similar results from Yegua Creek will enable broader generalizations regarding the impact of impoundments on streams. With construction of more dams planned for the state of Texas, as described in “Water for Texas: Highlights of the 2007 State Water Plan”

(2006), increased understanding of the overall potential effects of these dams is critical. In addition, the present study will aid in developing improved release practices in dam management to maintain sustainable, healthy river systems. Furthermore, his study provides a unique opportunity to gain insight about the interrelationships among the hydrological, morphological and sedimentological components of an impounded stream. This insight offers potential to augment our understanding of complex responses within environmental systems (Schumm, 1973).

CHAPTER III

STUDY AREA

Regional Setting

Yegua Creek, a tributary of the Brazos River, is located in south central Texas on the Gulf Coastal Plain (Fig. 1). The region has rolling to hilly topography with mildly to moderately alkaline clay and loam soils (Chervenka et al., 1981; Larkin and Bomar, 1983; Alvarez et al., 2004). Drainage basin elevation ranges from 51-199 m (Chin et al., 2002). The creek and its tributaries are underlain by recent alluvial floodplain deposits of clay, silt, sand and gravel which are crosscut northeast to southwest by the following formations beginning at the headwaters of Middle Yegua Creek: the Sparta Sand, Cook Mountain Formation, Yegua Formation, the Cadell Formation near Lake Somerville, the Manning Formation and the Catahoula Formation near the Brazos River (Proctor et al., 1974).

Yegua Creek drainage basin climate is similar to other surrounding areas. The region has a Subtropical humid, warm, temperate, climate. Annual temperatures (Fig. 2) average 20.2°C and range from 28.6°C to 8.9°C in July and January, respectively (Larkin and Bomar, 1983; Jennings, 1999; Chin and Bowman, 2005). Precipitation peaks in September and May with a mean annual of 1022.6 mm (Fig. 2). In addition, discharge peaks in May and June (Fig. 3).

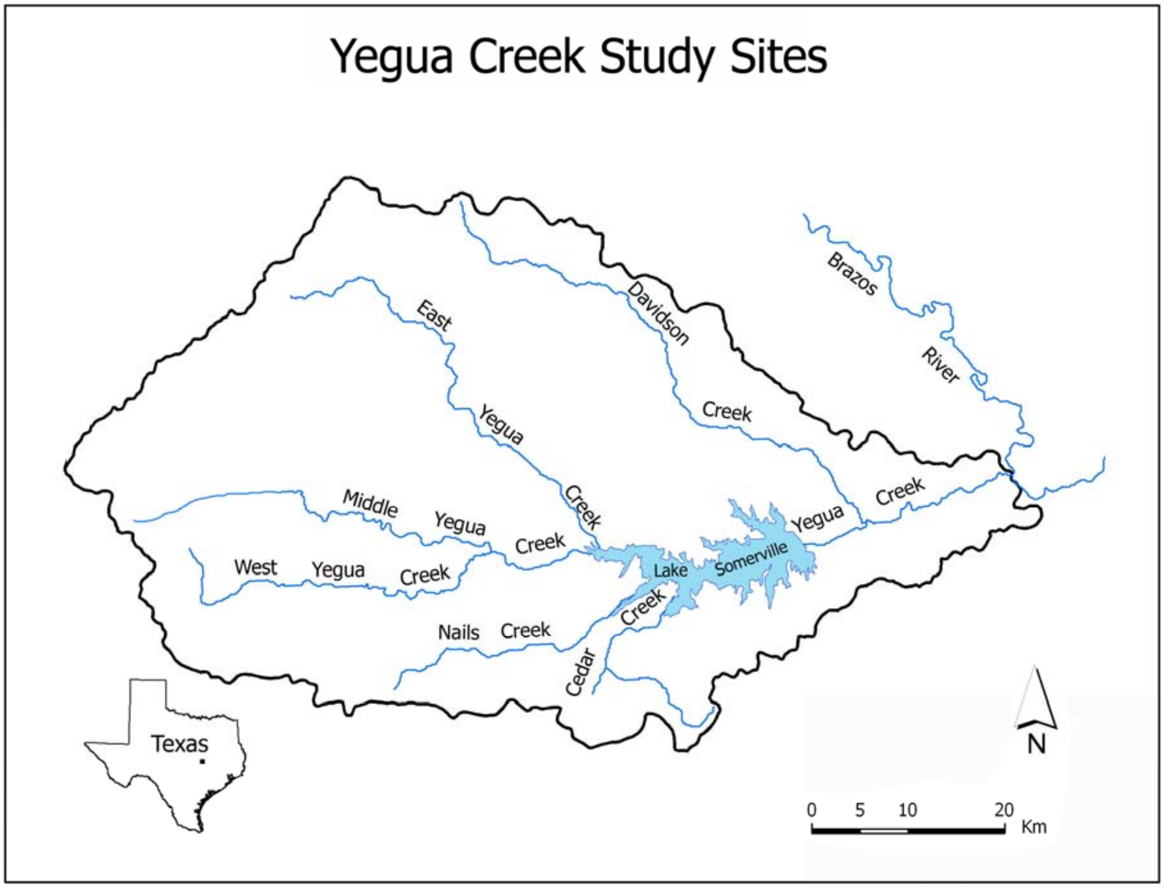

Fig. 1. Yegua Creek drainage basin.

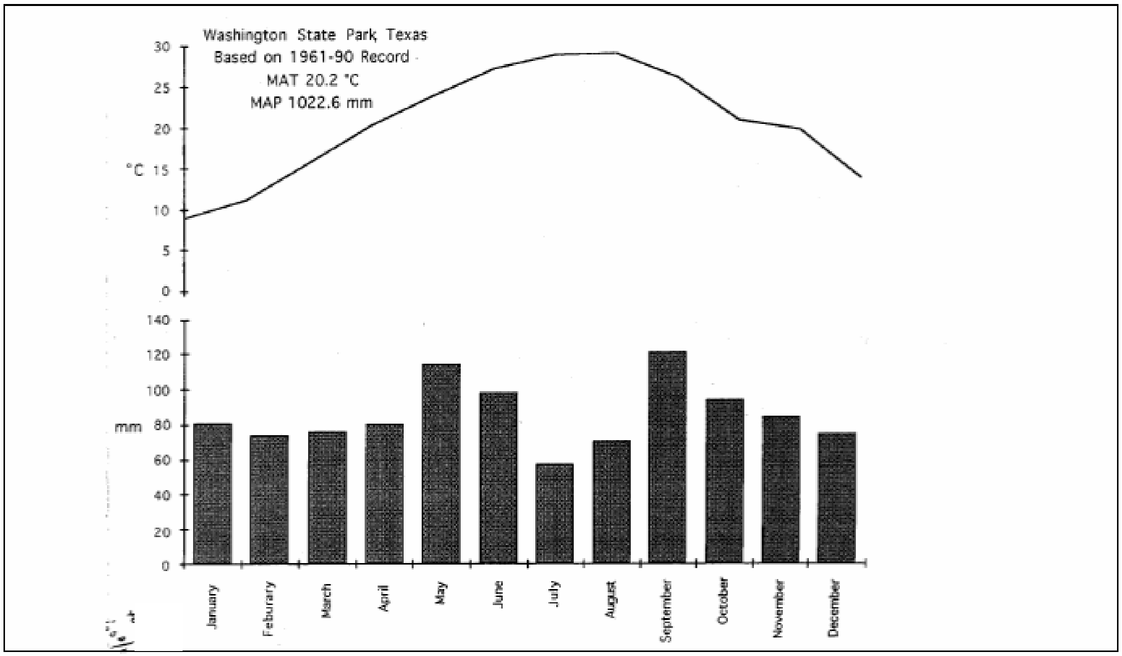

Fig. 2. Washington State Park Climograph (from Jennings, 1999).

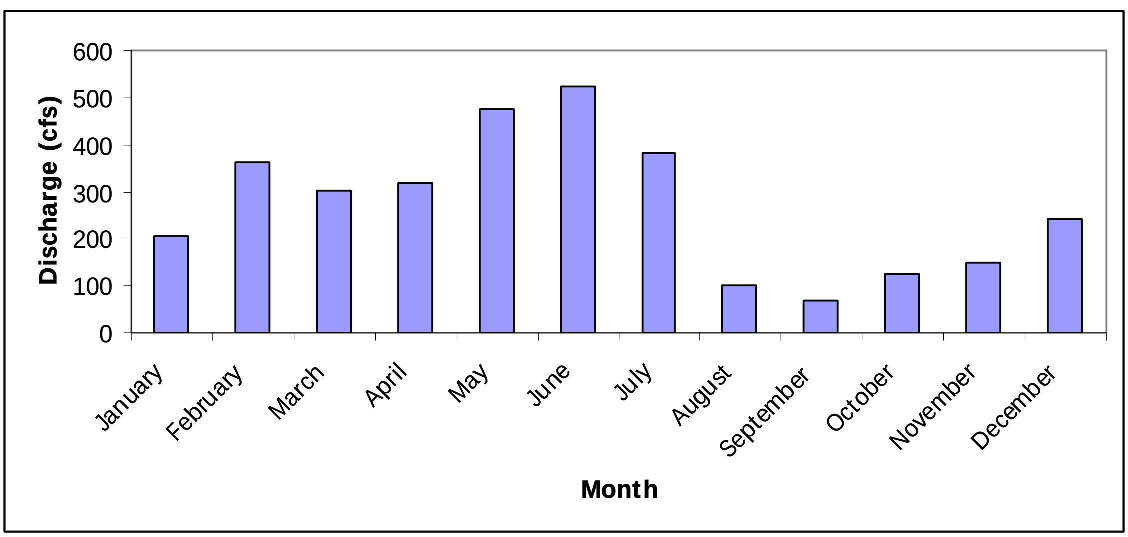

Fig. 3. Average monthly discharge, Yegua Creek downstream of Somerville dam. 1967-1991 (USGS, 2007).

Soil surveys of Washington County (southeast of Lake Somerville) and Lee County (west of Lake Somerville) show Kaufman soils, primarily consisting of clay and loam, surrounding Yegua Creek and all of its tributaries (Fig. 4). Upstream of Somerville Dam, Kaufman soils are surrounded primarily by fine sandy loam soils and loamy sand. Downstream of the dam, excessively fine, clayey soils surround the Kaufman soils (Burgess and Lyman, 1906; Chervenka et al., 1981).

The land uses in the area include agriculture and pasture. Broadleaf forests and Post Oak Savannah species surround Yegua Creek in areas that remain undisturbed (Jennings, 1999). Dominant species throughout the watershed include: *Quercus stellata* (Post Oak), *Q. marilandica* (Blackjack Oak), *Ilex vomitoria* (Yaupon), *Cephalanthus occidentalis* (Button Bush), *Planera aquatica* (Water Elm), *Ulmus occidentalis* (Ceder Elm) and *Carya aquatica* (Water Hickory) (Correll and Johnston, 1979; Chin et al., 2002).

Gaging stations provide information regarding flow data throughout the drainage basin. The United States Geological Survey (USGS) is an organization that provides information regarding geography, geology, geospatial information, biology and water. In the Water Resources division, USGS provides data and maps of surface and groundwater. The surface water database contains information regarding gaging stations. Four such gaging stations are located within Yegua Creek drainage basin. These gaging station are: 08110000, 08109800, 08110100 and 08109700 (Fig. 5). The primary purpose for these gaging stations is to provide flow data. Table 1 provides stations located throughout Yegua Creek drainage basin. Data from gaging station

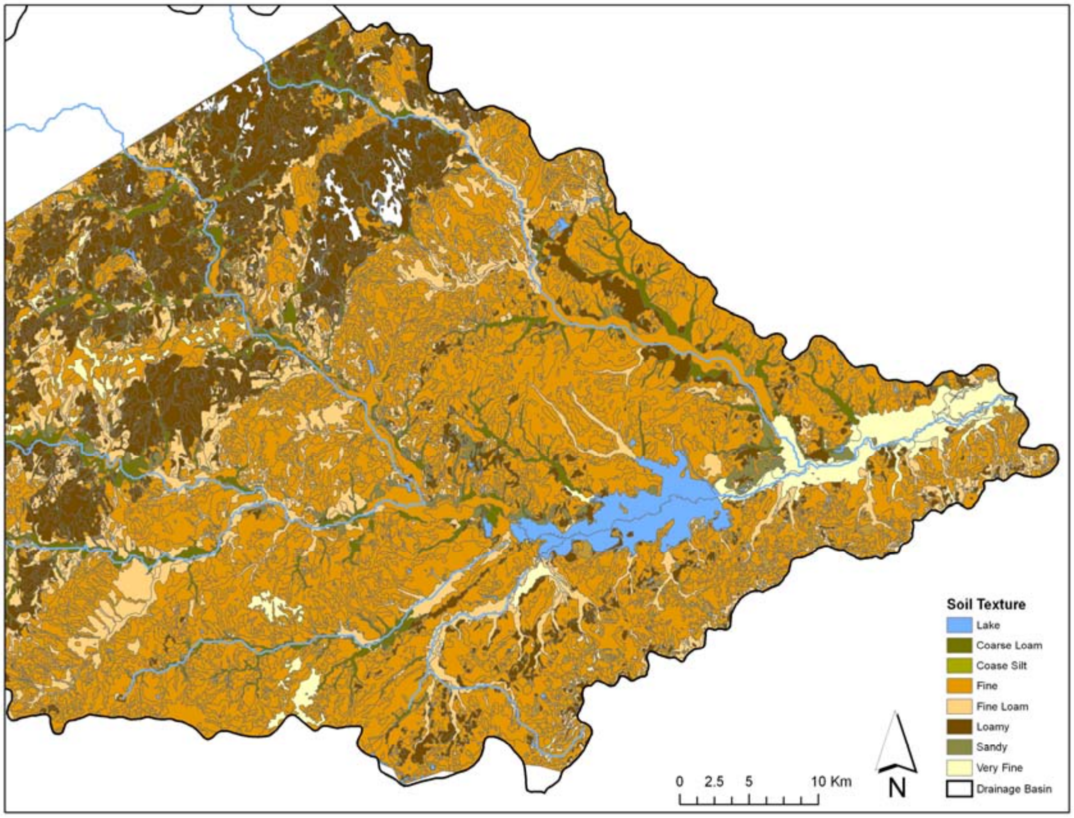

Fig. 4. Yegua Creek drainage basin soil survey.

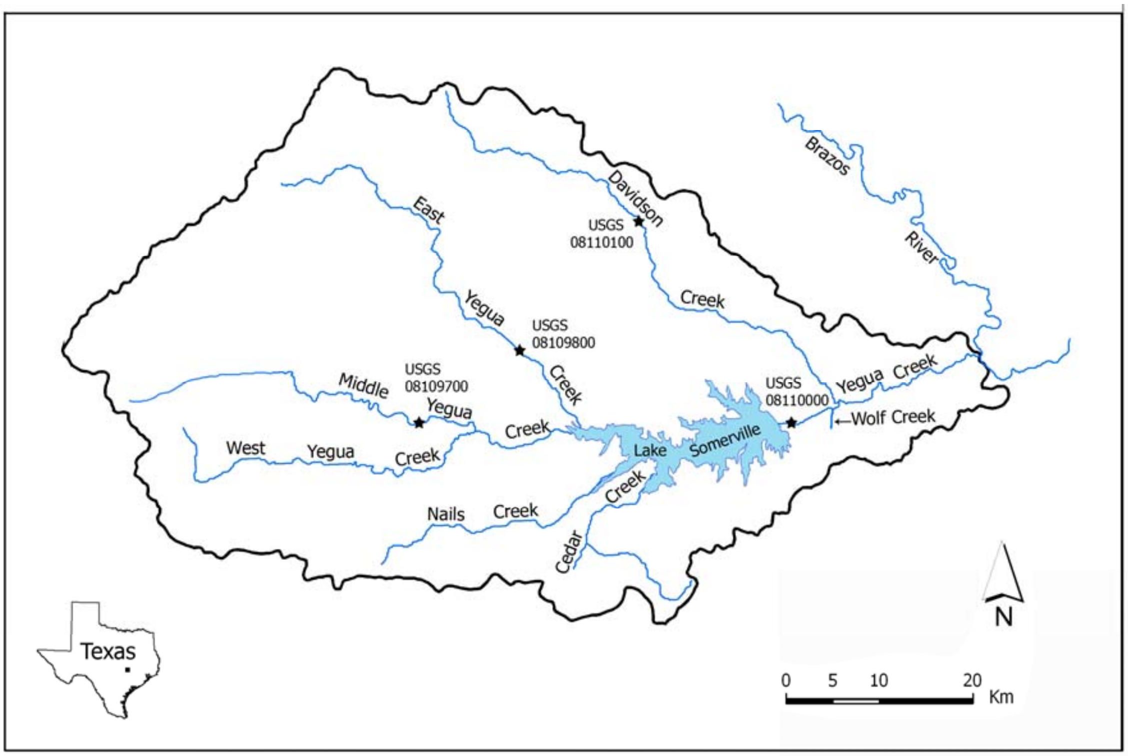

Fig. 5. USGS gaging stations, Yegua Creek drainage basin .

Table 1
USGS gaging station collection periods (USGS, 2007).

USGS Hydrologic Unit Code (HUC)	Location	Initial Data Collection Date	Final Data Collection Date
8109700	Middle Yegua Creek near Dimebox, Texas	August 1, 1962	ongoing
8109800	East Yegua Creek near Dimebox, Texas	August 1, 1962	ongoing
8110100	Davidson Creek near Lyons, Texas	October 1, 1962	ongoing
8110000	Yegua Creek near Somerville, Texas	March 24, 1924	September 30, 1991

information regarding dates of discharge and stage height collections at the four gaging 08110000, located just downstream of Somerville Dam are used to evaluate the effects of Somerville Dam on the sediment transport of Yegua Creek.

Analysis of changes in flow regime conducted by Chin et al. (2002) showed an 85% decrease in annual peak discharge after stream impoundment. Average annual peak flows decreased from 10,810 cfs (18,366 cms) before stream impoundment to 1,623 cfs (xxx cms) after impoundment (Fig. 6). Furthermore, flood frequency analysis revealed a decrease in flood magnitude for floods with return periods over 10 years (Fig. 7). Therefore, floods with the same recurrence interval before and after stream impoundment have reduced in magnitude (Chin et al., 2002).

The Yegua Creek Watershed

Yegua Creek is created by several major tributaries. Yegua Creek drainage basin area is 2,605.44 km^2. The upstream portion of the Yegua Creek drainage basin (Fig. 1) consists of Middle Yegua Creek (Fig. 8) and includes the tributaries East Yegua Creek (Fig. 9) and West Yegua Creek (Fig. 10). Nails Creek (Fig. 11) and Cedar Creek (Fig.12) south of Lake Somerville are the remaining main tributaries upstream of Somerville Dam. Downstream of Somerville Dam, Davidson Creek (Fig. 13) is the major tributary of Yegua Creek (Fig. 14-16), which joins with the Brazos River approximately 20 km downstream of Somerville Dam.

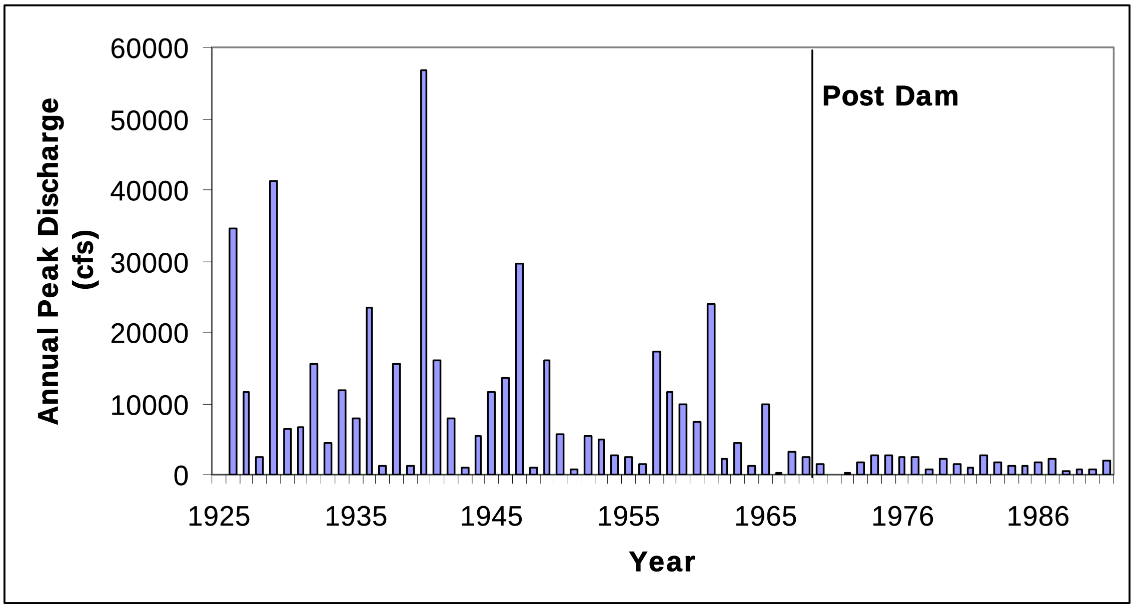

Fig. 6. Annual peak discharge 1925-1991 (after Chin et al., 2002).

Fig. 7. Flood frequency curve for Yegua Creek before and after stream impoundment (after Chin et al., 2002).

Fig. 8. Middle Yegua Creek.

Fig. 9. East Yegua Creek.

Fig. 10. West Yegua Creek.

Fig. 11. Nails Creek.

Fig. 12. Cedar Creek.

Fig. 13. Davidson Creek.

Fig. 14. Yegua Creek downstream Somerville Dam.

Fig. 15. Yegua Creek, Landolt Cross section B (Fig. 17), Spring 2007.

Fig. 16. Yegua Creek near its confluence with the Brazos River.

The characteristics of the channel morphology of Yegua Creek are as follows. The average channel slope throughout the basin is 0.0001. This slope value is consistent with coastal plain streams. Upstream of Lake Somerville, average width and depth are 13.1 m and 0.36 m, respectively. Downstream of Lake Somerville, the width and depth average 22.4 m and 0.65 m, respectively. The bed material consists of primarily fine grained, cohesive sediment (Chin et al., 2002). Field observations provided preliminary evidence of substantially coarser bed material throughout West Yegua Creek (Fig. 10), Nails Creek (Fig. 11) and lower Middle Yegua Creek (Fig. 8). Banks along Yegua Creek and its tributaries throughout Yegua Creek drainage basin are primarily stable. One notable exception is the eroding banks near the intersection of Yegua Creek and Highway 50 downstream of Somerville Dam (Fig. 17).

Somerville Dam

Construction of Somerville Dam on Yegua Creek began in early 1963; the dam started impounding water in 1967 (Fig. 18). The chief purposes of the dam are to control flooding on Yegua Creek, conserve water, and attract visitors to the area (Schaffer, 1974; Chin and Bowman, 2005). The dam has a life expectancy of 50 years, a conservation storage capacity of 177,498,000 m^3 (143,900 ac-ft), and a flood control storage capacity of 416,547,000 m^3 (337,700 ac-ft) (Chin et al., 2002). Somerville Dam is a large dam in the classification of the National Inventory of Dams (Chin et al., 2008).

Fig. 17. Unstable banks visible on Yegua Creek at Highway 50 crossing.

Fig. 18. Somerville Dam outlet and Yegua Creek.

Previous Work

Previous studies of Yegua Creek have documented the hydrological (Chin et al., 2002), morphological (Chin and Bowman, 2005), and ecological (Jennings, 1999) effects of Somerville Dam. A more equitable flow regime had developed after impoundment owing to a decrease in flood peaks (85%) and an increase in low flows. Furthermore, a 65% decrease in channel capacity, largely due to a 61% decrease in channel depth, was found downstream of Somerville Dam. Minimal change, only a 9% decrease, in channel width was apparently a result of increased bank stabilization through the development of riparian vegetation due to increased summer low flows (Chin et al., 2002). Jennings (1999) further documented increases in riparian vegetation along the banks in areas downstream of the dam.

Climatic differences before and after stream impoundment studied in previous research have been insignificant. Jennings (1999) found no difference in the mean annual precipitation before and after stream impoundment. Little difference was also found in the mean monthly precipitation. December was the only month to have a significant statistical difference. Therefore, precipitation has not changed significantly since impoundment. However, a significant change in the relationship between precipitation and discharge has occurred. Changes in precipitation were reflected in discharge before impoundment meaning increases or decreases in precipitation were reflected in discharge records. After impoundment, precipitation events had less influence on stream discharge (Jennings, 1999). This disconnection is likely caused by Lake Somerville which now retains any precipitation that would have previously altered stream discharge. Instead now, changes in discharge previously due to precipitation are masked by the dam. A comprehensive history on the creek and the construction of Somerville Dam was also reported in Chin and Bowman (2005). This study adds to those efforts by examining sedimentological effects of Somerville Dam.

CHAPTER IV

METHODS

General Approach

To answer the first question of whether sediment is passing through Somerville Dam, sedimentation rates of Lake Somerville (Fig. 1) between 1995 and 2003 were analyzed. These data are available from the U.S. Army Corp of Engineers (USACE, Lauderdale, personal communication). The sedimentation rates are derived from depth surveys of Lake Somerville in which the USACE determined the water volume capacity of the lake. These surveys were conducted in 1995 and in 2003. The water volume capacity loss is then computed to reveal the amount of sedimentation taking place between survey periods. All volume loss was assumed to be a result of sedimentation taking place behind Somerville Dam. Survey results for this study were preformed by the USACE in 1995 and 2003. In addition, the trap efficiency was calculated based on reservoir capacity and catchment area (Brune, 1953; Verstraeten and Poesen, 2000). Trap efficiency indicates the percentage of sediment no longer being transported through the dam. Instead, sediment supplied from the upstream portions of the basin and deposited in Lake Somerville is retained by the dam.

Field, laboratory, and aerial photograph analysis, as well as theoretical calculations, yield answers to the second research question: determine the extent to which present flows are capable of transporting sediment downstream of the dam. Analysis of bed and suspended sediment samples collected in the field at low flows forms the core of this portion of the study. In this study, low flows are defined as flows occupying approximately 25% of channel capacity and with a recurrence interval of three years or less, based on flood frequency analysis after (Fig. 7). Discharges were calculated by measuring cross sectional area and multiplying by measured velocity (Edwards and Glysson, 2005). Discharges for low flows averaged 0.31 cms and ranged from 0.02 cms to 0.6 cms (Table 2). Additional suspended sediment samples were collected at higher flows to gain insight into transport conditions during these events. Discharges for higher flow events (hereafter called “high”) were selected as flows approximately bankfull and those with recurrence intervals of approximately 6 years. High flow discharges averaged 15.64 cms with a range from 10.44 cms to 20.52 cms (Table 2). The high flows sampled represented the highest discharge measurable with conventional equipment under safe conditions.

Differences between the upstream and downstream sediment characteristics were documented. Laboratory analysis determined the sediment size distribution of the bed sediment as well as the suspended sediment concentration. The threshold of entrainment was calculated and compared against existing flow records to determine if effective flows capable of transporting sediment have occurred over the period of interest. Thus, movement of sediment can be inferred.

Finally, available aerial photographs provided additional evidence of the changes in size, location, and number of depositional and erosional features since impoundment. These aerial photographs corroborate mathematical calculations and field measurements.

Table 2
Cross sections and respective discharges at time of sampling.

Cross Section	Discharge (cms)			
	Low Flow	Date	High Flow	Date
Y36US	0.02	March 5, 2007	20.52	January 30, 2007
Y36DS	0.28	March 5, 2007		
Landolt A	0.36	February 17, 2007	10.44	May 18, 2007
Landolt B	0.31	February 17, 2007		
YC50	0.60	March 3, 2007	15.96	May 18, 2007
Average	0.31		15.64	

Data Acquisition and Preprocessing

The U.S. Army Corps of Engineers (USACE) and the United States Geological Survey (USGS) provided flow data for this study. These include gage height and discharge. Gaging station 08110000, the primary gaging station records used in this study is located downstream of Somerville Dam (Fig. xx). This station collected discharge and gage height between 1924 and 1991.

The USACE records of sedimentation rates for Somerville Dams for 1995-2003 were determined through lake volume surveys. Information regarding sedimentation rates is therefore limited to the time of surveying, which was conducted most recently in 1995 and again in 2003.

The Texas Natural Resource Information System (TNRIS) provided aerial photographs of Yegua Creek from their online database. TNRIS is a component of the Texas Water Development Board (TWDB) that provides the public with digital maps, aerial photographs and images of Texas. Photographs from the years 1995 and 2004 were determined appropriate for comparison, representing a nearly 10-year span. The TNRIS historical archives further provided images of Yegua Creek from 1958 and 1988. Images were not available for other dates. Furthermore, images for 1958 were only available for Yegua Creek near its confluence with the Brazos River and not near the dam site. Therefore, changes near the dam site and immediately downstream of the dam could not be interpreted. These photographs enabled the comparison of depositional and erosional features over time.

The aerial photographs required pre-processing as follows. First, the images were georeferenced into the same datum and projection (North American Datum 1983), preparing the images for analysis. These included the historical images obtained from TNRIS for the dates before 1995. These historical images were scanned at 1,000 dots per inch (dpi) and rectified to the 1995 and 2004 images already projected by TNRIS with 1 meter resolution. All images were projected into the Texas State Plane projection Zone 14N because it is the recognized projection of the state of Texas. It also provides the least amount of distortion in direction and distance for the study area (Dean, 2006). After georeferencing, these images were imported into a geographic information system [ESRI 9.1 (2005)] for analysis.

Field Procedures

Bed sediment and suspended sediment samples were collected at selected locations upstream and downstream of Somerville Dam during January, February and March 2007 for low flows and January and May 2007 for high flows. Twenty three cross sections along Yegua Creek represented the length of the channel (Fig. 19, Table 3). These were selected to be as evenly distributed as possible and to match those of previous studies on Yegua Creek (Chin et al., 2002). Because much of the study area is located on private property, the study sites were also constrained by accessibility. Thirteen of these cross sections are located upstream of the dam along Middle Yegua Creek and four of its tributaries: West Yegua Creek, East Yegua Creek, Nails Creek and Cedar Creek. An additional ten cross sections, six along Yegua Creek and four on

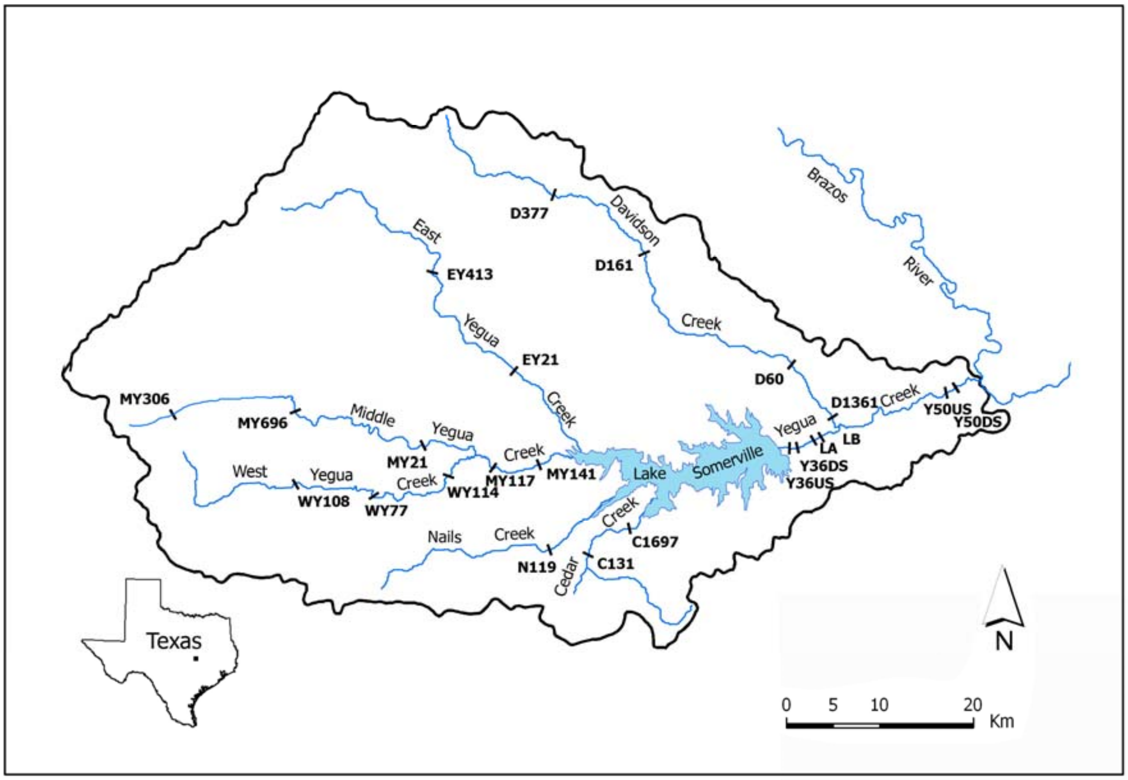

Fig. 19. Yegua Creek study site locations. (Cross section abbreviations refer to those found on Table 3).

Table 3
Cross section location abbreviations.

Cross Section Abbreviation	Cross Section Name
D377	Davidson Creek Hwy 377
D161	Davidson Creek Hwy 161
D60	Davidson Creek Hwy 50
D1361	Davidson Creek Hwy 1361
EY413	East Yegua Creek Hwy 413
EY21	East Yegua Creek Hwy 21
WY108	West Yegua Creek Hwy 108
WY77	West Yegua Creek Hwy 77
WY114	West Yegua Creek Hwy 114
N119	Nails Creek Hwy 119
C131	Cedar Creek Hwy 131
C1697	Cedar Creek Hwy 1697
MY306	Middle Yegua Creek Hwy 306
MY696	Middle Yegua Creek Hwy 696
MY21	Middle Yegua Creek Hwy 21
MY117	Middle Yegua Creek Hwy 117
MY141	Middle Yegua Creek Hwy 141
Y36US	Middle Yegua Creek Hwy 36 Upstream of Bridge
Y36DS	Middle Yegua Creek Hwy 36 Downstream of Bridge
LA	Landolt Cross Section A
LB	Landolt Cross Section B
Y50US	Yegua Creek Hwy 50 Upstream of Ramp
Y50DS	Yegua Creek Hwy 50 Downstream of Ramp

Davidson Creek (a tributary of Yegua Creek), are located downstream of the dam. Field work was conducted at low and high flows.

At each site a stable cross section was identified and the channel width and depth were measured. A tape measure was placed across the channel and depth was measured every few meters, depending on the width of the channel. Wider channels required more depth measurements to more accurately determine channel geometry. There were at least three depth measurements per channel cross section.

Velocity measurements were then taken at 0.6 of the depth at each respective location with a Marsh McBirney electromagnetic flow meter (Fig. 20). This enabled the determination of equal increments of discharge within the cross section to carry out the equal-discharge-increment (EDI) method. The EDI method enables representative suspended sediment sampling for each cross section. Equal increments of discharge are required to sample suspend sediment at intervals that would yield the average amount of suspended sediment throughout the crossection (Edwards and Glysson, 2005):

1. First the discharge of each width subsection was calculated by multiplying width, depth and velocity.
2. Next, the total discharge of the cross section was determined by totaling each subsections discharge. The total discharge was then divided by four. This would create four subsets of equal discharge from which to sample suspended sediment concentration (Edwards and Glysson, 2005).
3. Next, the width location for each equal discharge was interpolated using the initial discharge measurements and their respective sample location (Fig. 21).

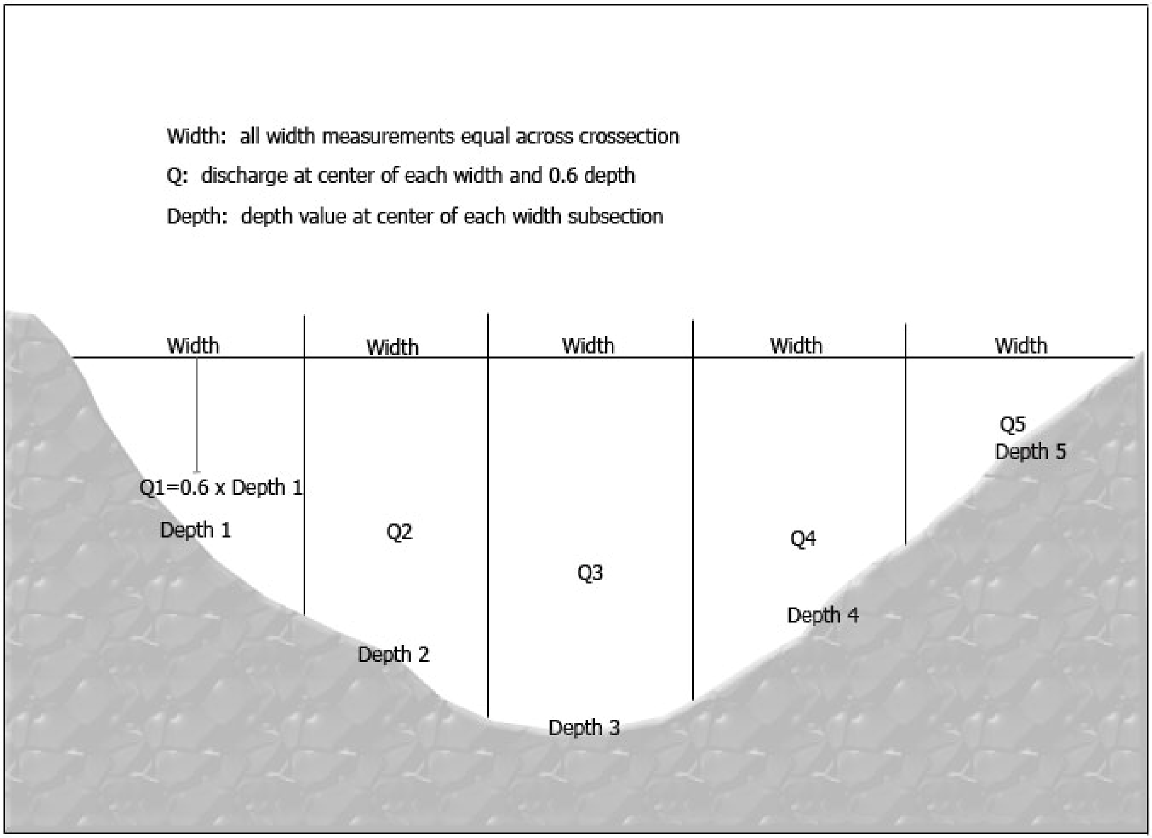

Fig. 20. Placement of width, depth, and velocity measurements to determine discharge (after Edwards and Glysson, 2005).

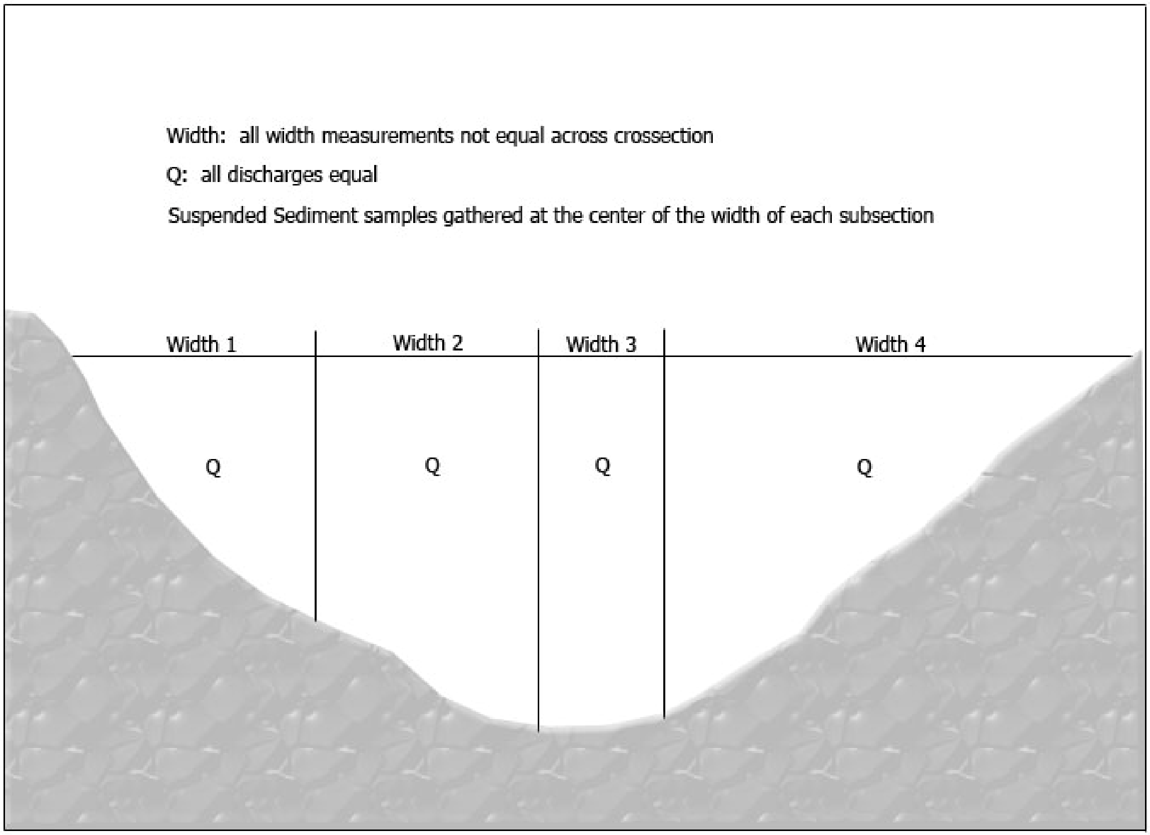

Fig. 21. Suspended sediment sample locations (after Edwards and Glysson, 2005).

Finally, suspended sediment samples were gathered with an integrating suspended sediment sampler (DH 48). These were sampled at the center of the width of each of the four interpolated subsections along the stream cross section. The DH 48 was lowered at a constant rate to the bottom of the channel and then lifted at the same constant rate to gain a representative suspended sediment sample. A total of 108 suspended sediment samples were gathered throughout the drainage basin.

An average of three bed sediment samples from each cross section were collected using a hand core sediment sampler every 1-3 meters across the channel depending on the width of the channel. One bed sediment sample was obtained from the thalweg of the channel and two an equal distance from the thalweg to the bank on both the left edge and right edge of water. Each bed sediment sample cored sediment approximately six inches into the bed. A total of 76 bed sediment samples were taken throughout the drainage basin. A Global Positioning System provided additional locational information.

Laboratory Methods

Suspended sediment samples were processed in the Texas A&M Geography Department Sediment Lab. To determine suspended sediment concentration, each sample was filtered and weighed. The concentrations of the suspended sediment above and below Somerville Dam were then compared to infer the effects of the dam.

Suspended sediment analysis followed procedures outlined in the American Society for Testing and Materials (ASTM) “Standard Test Methods for Determining Sediment Concentration in Water Samples” (ASTM, 2006), as follows:

1. The empty sample bottles were first weighed to obtain their tare weight, or their weight prior to sediment filtration.
2. Sample bottles were then weighed after obtaining the sample to determine their gross weight. Subtracting the tare weight (from step 1) from the gross weight of the sample yielded the net weight of the sample.
3. Then, to filter the sample, oven dried (for one hour at 100°C, 25 mm glass microfiber filters were placed in Gooch Crucibles and weighed to determine their tare weight.
4. The Gooch Crucibles and filters were then used to filter the suspended sediment sample.
5. After oven drying the filters and Gooch Crucibles again, the filters, sediment and crucible were weighed to determine the gross weight. The tare weight of the crucible and filter obtained in step 3 was subtracted from the gross weight to determine the net weight of the sediment.
6. Finally, the following equation yielded the concentration of suspended sediments in parts per million (ppm):

$$\text{Concentration (ppm)} = \frac{net\ weight\ of\ sediment}{net\ weight\ of\ sample} \times 1{,}000{,}000 \qquad (1)$$

Bed sediment samples were processed in the Soil Characterization Lab at Texas A&M University. Analysis proceeded along the guidelines outlined in Steele and Bradfield (1934) and Kilmer and Alexander (1949), and summarized recently in Kondolf and Piegay (2003). Bed sediment samples obtained from the field were first air dried for approximately 1 week, ground and catalogued. Separate procedures were required to determine the size distribution for particles larger than 2 mm (coarse fragments), particles between 0.05 mm and 2 mm (sand) and those smaller than 0.05 mm (silt and clay). First, particles larger than 2 mm were separated out. In order to process sediment smaller than 2mm the following procedures were preformed:

1. Ten gram samples of the remaining sediment were placed each in separate sedimentation bottles. These ten gram samples were then mixed with 5 mL of a dispersing agent (calgon) and filled with distilled water. They were placed in a reciprocating shaker for 24 hours.
2. After 24 hours, a magnetic spin bar was added and the temperature of each bottle was recorded.
3. Sedimentation bottles were then placed on a magnetic stirring plate and stirred for exactly two minutes.
4. After the two minute time period, bottles were placed in a water bath and the sediment mixture was allowed to settle for approximately 2 minutes. The exact settling time was determined using stokes law and the measured temperature of the mixture prior to stirring. After the appropriate time, 5 mL was pipetted out and placed in a crucible.

5. Three hours later, the pipet procedure was repeated. Again, the precise settling time was determined based on the temperature of the sediment mixture in the bottles.
6. Crucibles were oven dried and weighed. These procedures yield the size distribution of the sediments finer than 0.05 mm.

The remaining sample in the sedimentation bottles, that greater than 0.05 mm (sand) was processed using the procedures outlined by Ward and Harr (1990) to determine the sediment size distribution:

1. Sediments were first washed and sieved through a size 300 mesh sieve. This discarded any silt and clay still left in the sediment sample in order to determine sand size distribution.
2. The remaining sand was oven dried and sieved with a ro-tap shaker using the mesh sizes found on Table 4 (Folk, 1980). The mass of sediment in each sieve was recorded.

Finally, the sediment fraction larger then 2mm (coarse fragments) was weighed and these weights recorded to determine the percentage of coarse fragments at each cross section.

Table 4.
Mesh sizes used during sand distribution analysis.

Mesh #	**Sediment Size**	**Phi (Φ)**
#18	1 mm	0
#35	0.5 mm	1
#60	0.25 mm	2
#140	0.10 mm	3.25
#300	0.05 mm	4.395

Theoretical Calculations

To calculate the sediment trap efficiency of Lake Somerville, the following equation was calculated used. It is developed by Brown (1943) and reported in Verstraeten and Poesen (2000).

$$TE = \quad 100\left[1 - \frac{1}{1 + D(\frac{C}{W})}\right] \tag{2}$$

TE = trap efficiency (%)

D = constant

Can range from 0.046 to 1 with a mean of 0.1. A constant of 1 applies for regions with variable runoff and reservoirs that store flood flows. Therefore, 1 was used to determine the trap efficiency of Somerville Dam (Brown, 1943; Brune and Allen, 1941; Heinemann, 1984; Verstraeten and Poesen, 2000)

C = reservoir capacity (ac-ft)

W = catchment area (miles^2)

The trap efficiency equation was developed using 23 reservoirs from Texas to Ohio as the core of the Brown (1943) study. Factors that may influence reservoir sedimentation include the following: the rate of sediment delivery based on erosion, the ratio of capacity to drainage area of the reservoir, the range of sediment particle sizes, shape of the reservoir, and reservoir purpose. Brune and Allen (1941) stated that the most important factor among these was the ratio capacity to drainage area. Furthermore, Brown (1943) suggested plotting reservoir sedimentation against catchment area because it is an easily determinable variable. Therefore, the equation relates trap efficiency to the capacity-catchment area ratio.

Phillips (2003) and Phillips et al. (2004) developed the following equation for sediment yield based on reservoir surveys obtained from the Texas Water Development Board (TWDB). The bulk density of sediments deposited in to the lake is assumed to be 1 Mg/m^3 (Welborn, 1967; Williams, 1991; Smith et al., 2002; Phillips et al., 2004). The loss of water volume was assumed to be a decrease in lake capacity due to sedimentation (Phillips, 2003). Reservoir surveys were conducted in 1995 and again in 2003 by determining the elevation of the lake bottom at specific, fixed locations. These differences in elevation were noted and volume loss inferred. No survey has been conducted since 2003.

$$\text{Sediment Yield} = \frac{Volume\ Loss}{Drainage\ Area \times Years\ Between\ Surveys} \qquad (3)$$

Sediment Yield = $m^3/km^2/yr$

Volume Loss = total amount of water volume loss between surveys (m^3)

Drainage Area = km^2

Years Between Surveys = 1995-2003 (9 years)

After determining the particle size distribution through laboratory procedures, the median grain size (d_{50}) at each cross section was obtained by plotting the cumulative particle size distribution frequency. The median grain size is the particle size diameter in which 50% of the sediment by weight is larger, and 50% is smaller (Gordon et al., 2004). In other words, it is the median diameter of the sediment sample. In addition, d_{84}, d_{16}, d_{90}, d_{10}, d_{75} and d_{25} were determined. The d_{84} value, for example, is the 84th percentile, or the particle size diameter in which 84% of the sediment by weight is smaller and is one standard deviation away from the mean (Gordon et al., 2004).

To calculate the standard deviation, mean, skewness, and kurtosis of the particle size distribution at each cross section these values were converted into standardized phi (φ) scale values (Table 5) using the following equation (Gordon et al., 2004):

$$\text{Phi } (\phi) = \frac{\log(n)}{\log(2)} \tag{4}$$

n = particle size (mm)

Finally, the standard deviation, mean, skewness and kurtosis were calculated using the following equations (Gordon et al., 2004):

$$\text{Mean} = \frac{\phi 84 + \phi 16}{2} \tag{5}$$

$$\text{Standard Deviation} = \frac{\phi 84 - \phi 16}{2} \tag{6}$$

$$\text{Skewness} = \frac{\phi 84 - \phi 50}{\phi 84 - \phi 16} - \frac{\phi 50 - \phi 10}{\phi 90 - \phi 10} \tag{7}$$

$$\text{Kurtosis} = \frac{\phi 90 - \phi 10}{1.9(\phi 75 - \phi 25)} \tag{8}$$

The following calculations yield the shear stresses required for entrainment at each cross section. The shield's equation yields the critical shear stress (λ_c) required to move a particle of a specific size (Shields, 1936, Gordon et al., 2004):

$$\lambda_c=\theta_c g d(\rho_s-\rho) \tag{9}$$

θc= Shield's parameter, 0.056

g=gravity, 9.8 m/s^2

d=diameter of particle (m)

ρ_s= particle density, 2650 kg/m^3

ρ=density of water, 1000 kg/m^3

The value for the Shield's parameter (θc) indicates flow conditions that are either hydraulically smooth or rough. For hydraulically smooth conditions, laminar flow is presumably occurring whereas the hydraulically rough conditions correspond to turbulent flows. The Shield's parameter ranges between 0.04 and 0.06 with an average of 0.044. A value of 0.056 was elected for this study. This value is considered a "transition zone" between hydraulically smooth and hydraulically rough conditions (Gordon et al., 2004). Because the Shield's parameter is dependent on sediment particle cohesiveness, imbrication and sediment armoring, it may underestimate the shear stresses required to move clay sized particles (Gordon et al., 2004). The critical shear stress required to move a particle was calculated for both median (d_{50}) and coarse (d_{84}) particle sizes at each of the cross sections downstream of Somerville Dam.

To determine the shear stresses of the flows at USGS gaging station 08110000 (Fig. 5, Table 2), the following equation was used:

$$\lambda = \rho g d S \tag{10}$$

ρ= density of water, 1000 kg/m^3

g=gravity, 9.8 m/s^2

d= stage height (m)

S=slope = 0.0001

The flow data from USGS reports gage heights, which represent d in the equation. The shear stress for each respective stage height was then compared against the shear stress needed to entrain d_{50} and d_{84} sediment particles found using equation 9. This determined how often shear stresses capable of transporting sediment were present.

Aerial Photograph Analysis

Aerial photographs were analyzed within a Geographic Information System (GIS) for evidence of erosional and depositional processes and features. Depositional features (such as sand bars, aggredations and cutbanks) clearly identifiable in the aerial photographs were digitized. First, a criteria based on pixel digital number values for all bands supplied within the aerial photograph was developed for each year for consistent digitizing of features. This identified a threshold to define depositional features as areas that are absent of vegetation and thus have a higher reflectance than surrounding vegetated areas and water. To accomplish this, aerial photographs were reviewed and, in conjunction with field observations, depositional features were identified. The pixel digital number values for these depositional features were determined and used as a criteria to identify other bars along the creek for the same year of aerial photographs. Due to the low resolution in the historical photographs and varying stage heights, only qualitative changes in features were ultimately able to be recorded. These observations nevertheless corroborate the quantitative results obtained from field and laboratory analyses.

CHAPTER V

RESULTS

Sediment Characteristics

Bed Sediment

The size distributions of bed sediment from Yegua Creek upstream and downstream of Somerville Dam are reported in Table 5. These results were plotted on a cumulative particle size distribution curve to determine the median particle size (50th percentile, d_{50}), and coarse particle size (84th percentile, d_{84}), as well as d_{10}, d_{16}, d_{25}, d_{75}, d_{90} (Fig. 22-26). Values for each of the percentiles are shown on Table 6. Median sediment sizes throughout the drainage basin were primarily sands, with the exception of just below Somerville Dam, where clays dominated channel bed sediment. Coarse (d_{84}) sediment sizes show a concentration of very coarse sediment in West Yegua Creek and lower Middle Yegua Creek.

Middle Yegua Creek had an average median sediment size of 0.65 mm and sediment range from 1.49 mm to 0.07 mm (Fig. 27). This is classified as very coarse sands to very fine sands (Fig. 28). Coarse sediment sizes at this location average 1.26 mm and range from 0.20 mm to 2mm (Fig. 29), or fine sands to very coarse sands (Fig. 30). Middle Yegua Creek sediment size distributions also show an increase with distance from headwaters. This is followed by a gradual decrease (Fig. 31).

Table 5.
Particle size distribution.

Cross Section Location	Total Clay <0.002 (mm)	Fine Silt 0.002-0.02 (mm)	Coarse Silt 0.02-0.05 (mm)	Very Fine Sand 0.05-0.1 (mm)	Fine Sand 0.1-0.25 (mm)	Medium Sand 0.25-0.5 (mm)	Coarse Sand 0.5-1.0 (mm)	Very Coarse Sand 1.0-2.0 (mm)	Coarse Fragments >2.0 (mm)
	Particle Size								
D377	2.80	0.88	0.56	4.78	34.50	7.11	2.99	2.39	44.00
D161	13.86	6.26	3.49	11.99	37.52	9.81	2.42	1.98	12.67
D60	7.53	4.32	3.76	15.24	46.79	12.76	2.15	0.75	6.67
D1361	5.30	2.44	2.11	8.04	40.05	11.60	2.16	3.62	24.67
EY413	26.47	18.45	8.28	6.04	24.32	11.88	2.24	1.32	1.00
EY21	18.14	6.08	4.30	14.81	43.20	8.76	0.97	0.74	3.00
WY108	12.19	6.63	5.43	11.62	22.78	10.27	5.25	3.85	22.00
WY77	4.33	1.69	0.76	2.60	12.67	18.05	9.92	6.99	43.00
WY114	2.00	0.89	0.97	2.11	10.98	17.88	15.18	6.99	43.00
N119	3.49	1.10	0.69	3.06	9.85	8.75	5.71	2.69	64.67
C131	3.67	1.46	0.24	1.16	5.92	33.18	16.86	5.51	32.00
C1697	5.03	1.07	0.35	3.49	22.04	40.18	16.60	5.57	5.67
MY306	15.73	9.34	6.93	18.59	32.83	9.15	2.16	0.57	4.67
MY696	2.72	1.03	0.73	2.35	32.02	55.92	4.40	0.17	0.67
MY21	2.38	1.25	1.30	2.37	10.67	14.00	8.06	8.61	51.33
MY117	4.49	2.09	1.63	5.47	14.91	9.04	7.75	5.61	49.00
MY141	8.92	3.76	4.34	9.33	19.13	23.93	9.17	3.79	17.67
Y36US	55.60	25.30	2.95	5.45	6.55	2.25	1.05	0.80	0.00
Y36DS	53.70	26.45	3.30	6.10	7.75	2.05	0.50	0.15	0.00
LA	31.20	11.40	2.40	3.30	26.90	22.60	2.00	0.20	0.00
LB	26.88	8.94	2.39	12.39	38.64	9.17	0.90	0.40	0.33
Y50US	16.50	5.70	4.20	18.60	49.10	5.50	0.30	0.10	0.00
Y50DS	11.85	3.94	1.39	1.42	16.65	47.18	15.73	1.16	0.67

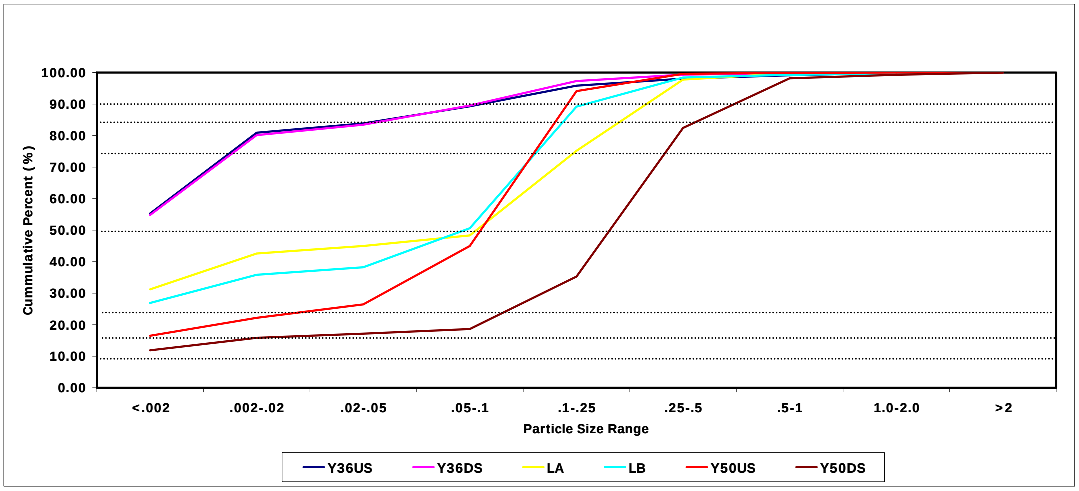

Fig. 22. Yegua Creek cumulative particle size distribution curves (Cross Section abbreviations refer to those found on Table 3).

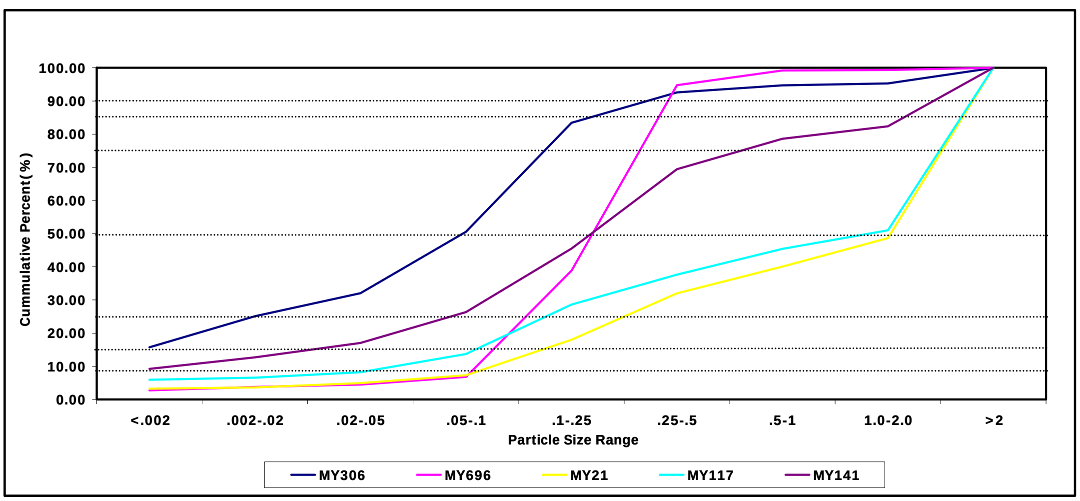

Fig. 23. Middle Yegua Creek cumulative particle size distribution curves (Cross Section abbreviations refer to those found on Table 3).

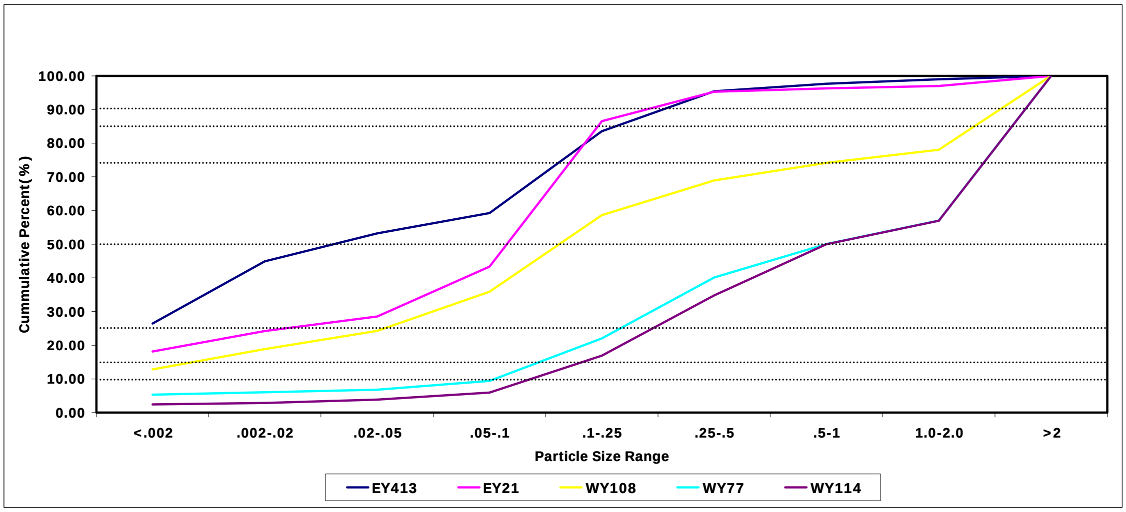

Fig. 24. East and West Yegua Creek cumulative particle size distribution (Cross Section abbreviations refer to those found on Table 3).

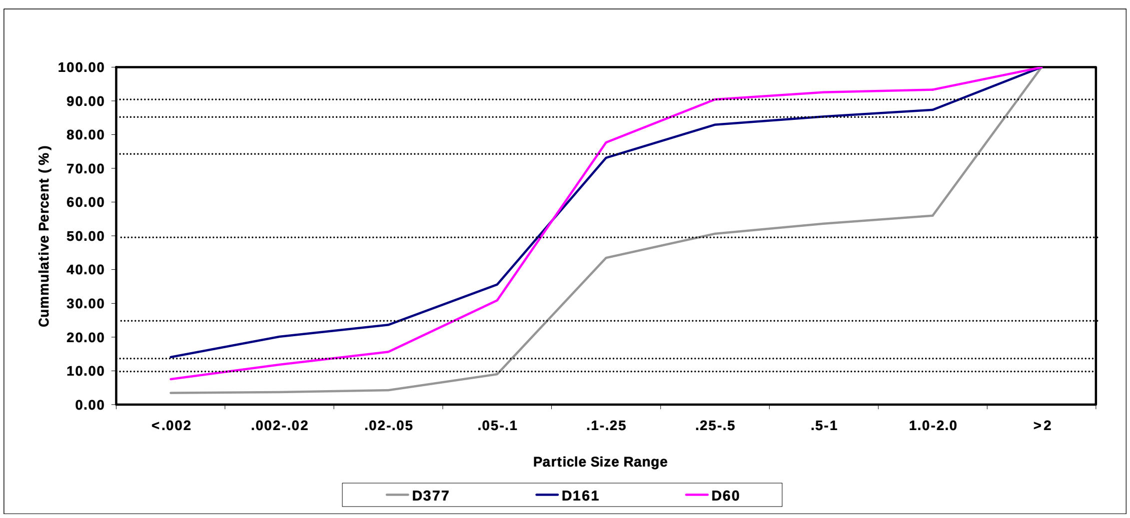

Fig. 25. Davidson Creek cumulative particle size distribution curves (Cross Section abbreviations refer to those found on Table 3).

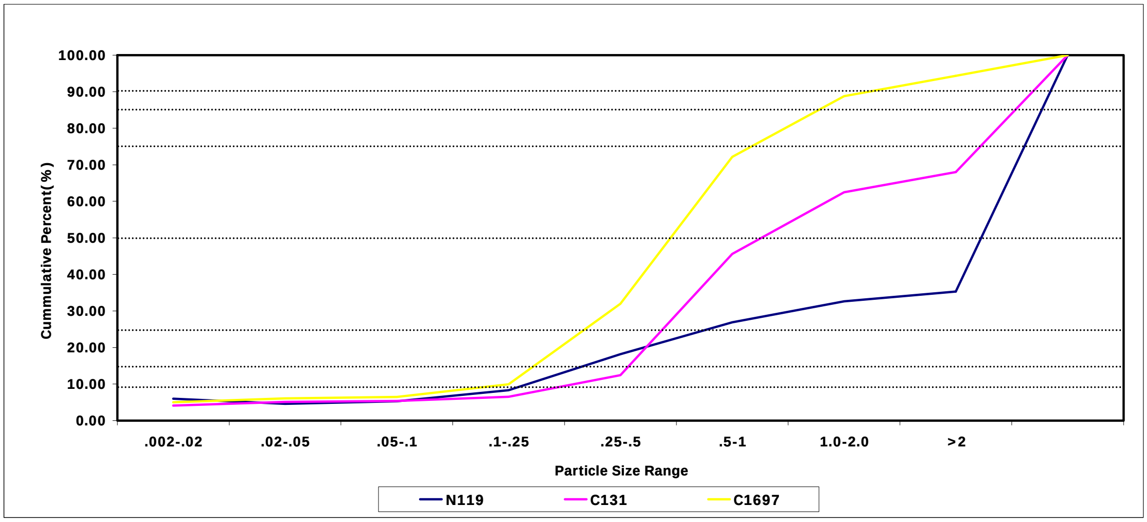

Fig. 26. Nails and Cedar Creek cumulative particle size distribution curves (Cross Section abbreviations found on Table 3).

Table 6.
Cumulative particle size values (Cross Section abbreviations refer to those found on Table 3).

Cross section	Diameter Values						
	d_{10} (mm)	d_{16} (mm)	d_{25} (mm)	d_{50} (mm)	d_{75} (mm)	d_{84} (mm)	d_{90} (mm)
D377	0.075	0.086	0.09	0.34375	1.9	2	2
D161	0.0003	0.0015	0.038	0.094	0.2125	0.6875	1.68
D60	0.004	0.035	0.05	0.095	0.16	0.3	0.375
D1361	0.035	0.04	0.82	0.1375	1.5	2	2
EY413	0.0001	0.00001	0.0015	0.022	0.11875	0.19	0.25
EY21	0.00001	0.04	0.013	0.82	0.135	0.17	0.23125
WY108	0.00001	0.004	0.035	0.109	0.09	1.75	2
WY77	0.08	0.11	0.19	0.6875	2	2	2
WY114	0.09	0.175	0.24	0.6875	2	2	2
N119	0.08	0.145	0.3125	1.625	2	2	2
C131	0.115	0.19	0.22	0.4375	1.625	2	2
C1697	0.075	0.089	0.115	0.24	0.42	0.625	0.75
MY306	0.00001	0.001	0.007	0.06875	0.1375	0.2	0.3
MY696	0.08	0.09	0.12	0.2	0.29	0.33	0.33
MY21	0.085	0.17	0.25	1.49	0.9	2	2
MY117	0.05	0.08	0.1375	1.3	2	2	2
MY141	0.0015	0.006	0.068	0.2	0.6	1.75	1.85
Y36US	0.00001	0.00001	0.00001	0.000625	0.008	0.0425	0.08
Y36DS	0.00001	0.00001	0.00001	0.000625	0.008	0.0425	0.08
LA	0.00001	0.00001	0.00001	0.075	0.18	0.22	0.27
LB	0.00001	0.00001	0.0009	0.07	0.115	0.145	0.19
Y50US	0.00001	0.001	0.02	0.08	0.115	0.1375	0.145
Y50DS	0.0005	0.012	0.09	0.22	0.33	0.43	0.5

West Yegua Creek, a tributary of Middle Yegua Creek, has an average of 0.49 mm sediment sizes (Fig. 27). These range from 0.11 mm to 0.69 mm, and are classified as coarse sands (Fig. 28). Coarse sediment sizes (d_{84}) average 1.92 mm and range from 1.75 mm to 2mm (Fig. 29), or very coarse sands (Fig. 30). The sediment sizes in West Yegua Creek increase with distance from the headwaters (Fig. 31).

Other tributaries of Lake Somerville include East Yegua Creek, Nails Creek, and Cedar Creek. Average median sediment size on East Yegua Creek is 0.42 mm, with a range of 0.02 mm to 0.08 mm, or fine sands to coarse sands (Fig. 27 and 28). Coarse (d_{84}) sediment sizes along East Yegua Creek average 0.18 mm and range from 0.19 mm to 0.17 mm, and are classified as fine sands (Fig. 32 and 33). East Yegua Creek sediment sizes show a slight increase with distance downstream (Fig. 31). Sediment analysis on Nails Creek showed a median sediment size classification of very coarse sands, or 1.63 mm (Fig. 27 and 28). Coarse (d_{84}) sediment sizes on Nails Creek was 2 mm, or very coarse sand (Fig. 32 and 33). Median sediment size on Cedar Creek averaged 0.34 mm and ranged from 0.44 mm to 0.24 mm (Fig. 27). These sediment sizes are classified as medium sands to fine sands (Fig. 28). Coarse sediment sizes average 1.31 mm and range from 0.63 mm to 2 mm and is classified as very coarse sands to coarse sands (Figures 32 and 33). Cedar Creek sediment sizes show a decrease with distance from headwaters (Fig. 31).

The average sediment size of Davidson Creek is 0.18 mm and ranges from 0.09 mm to 0.34 mm (Fig. 27). These are classified from medium sand to very coarse sand

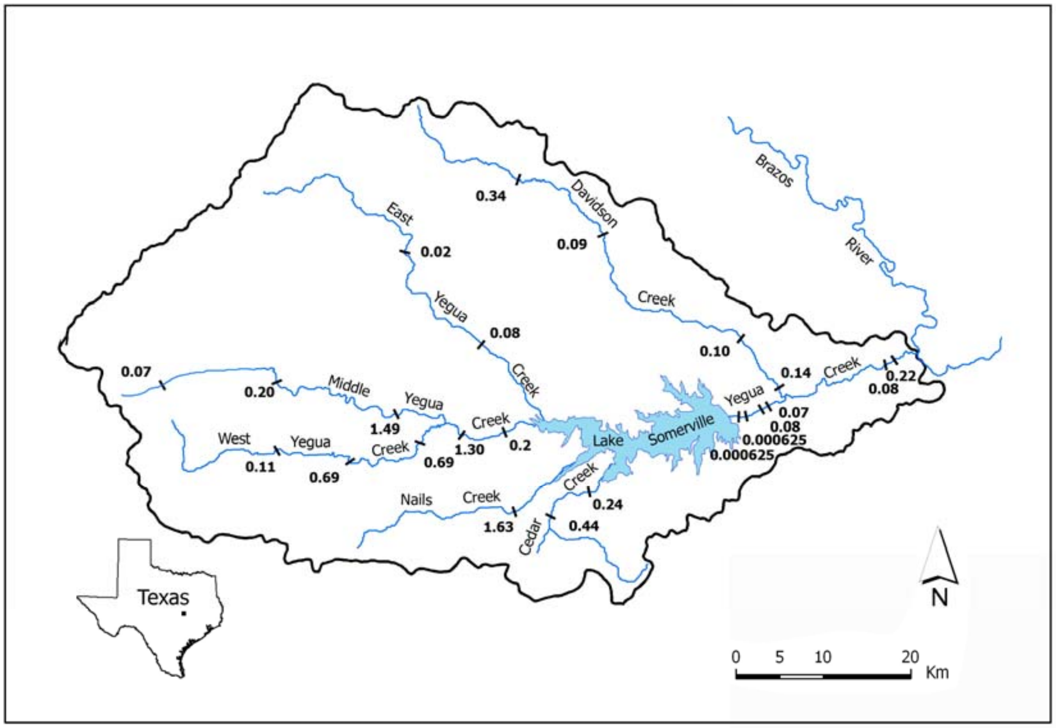

Fig. 27. Median (d_{50}) bed sediment sizes (mm), Yegua Creek drainage basin.

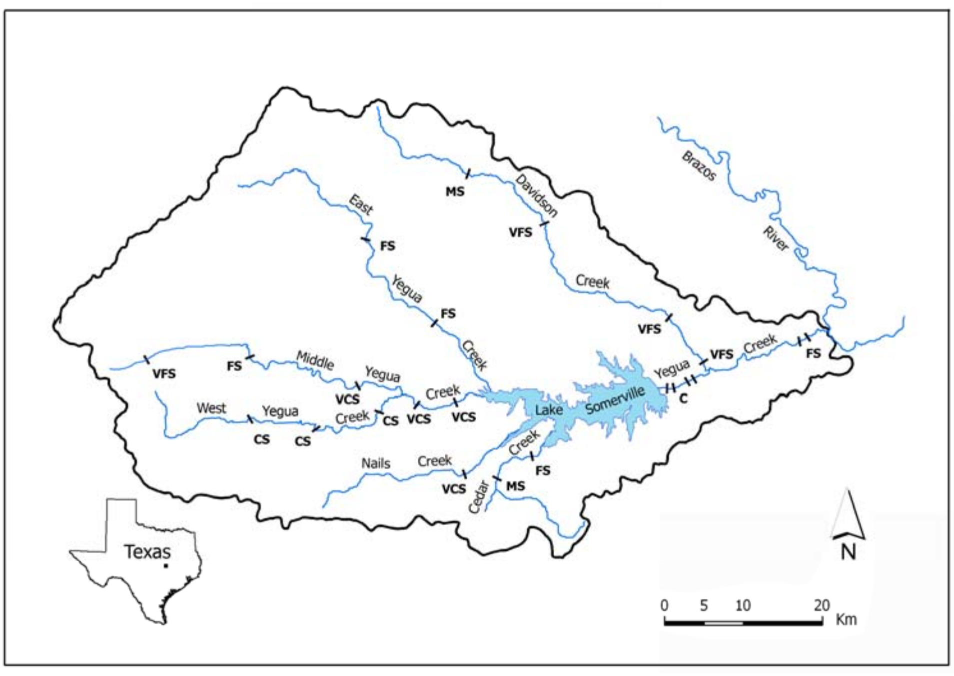

Fig. 28. Median (d_{50}) bed sediment size classifications (VCS= very coarse sand, CS= coarse sand, MS= medium sand FS= fine sand, VFS= very fine sand, C=Clay).

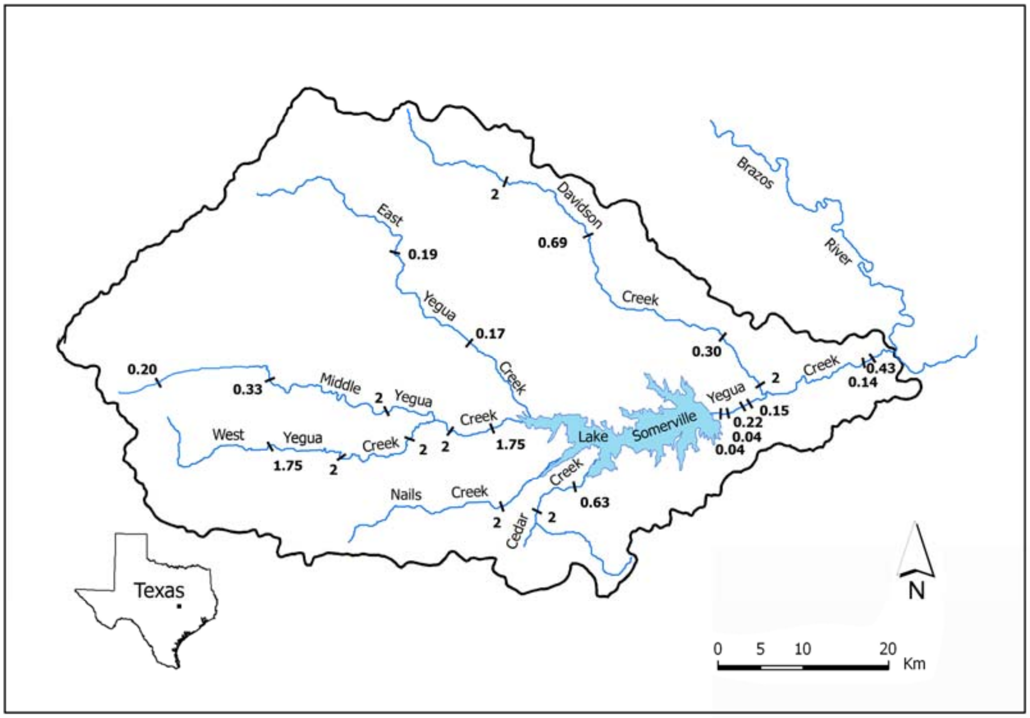

Fig. 29. The 84th percentile (d_{84}) bed sediment sizes (mm), Yegua Creek drainage basin.

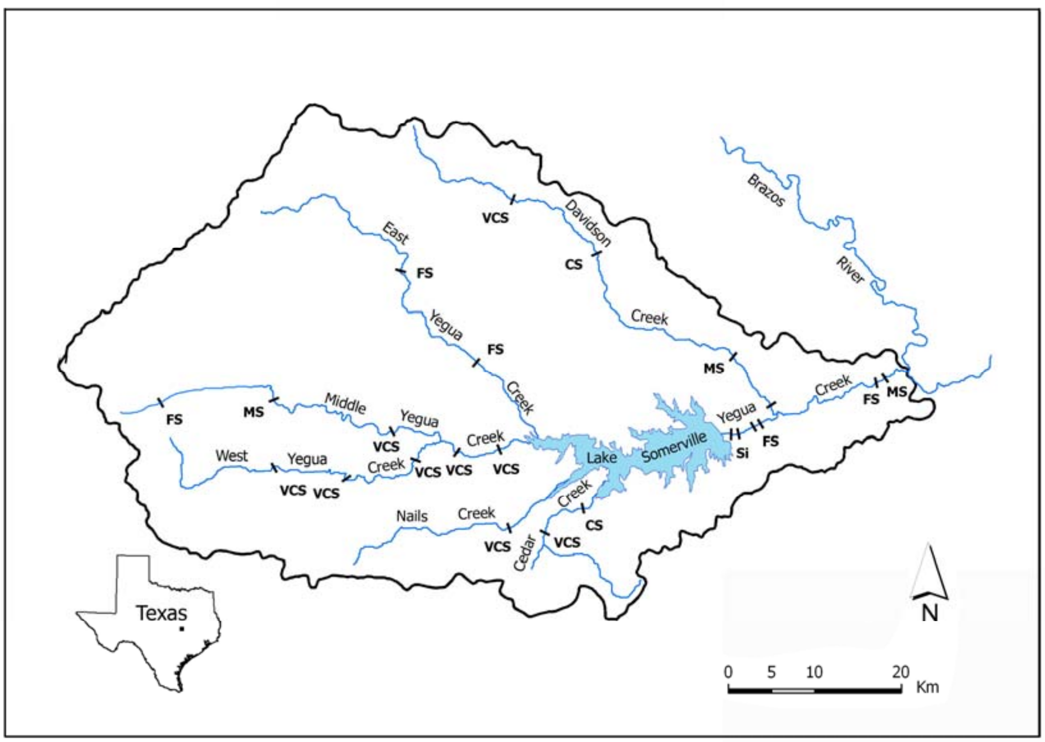

Fig. 30. The 84th percentile (d_{84}) bed sediment size classification (VCS= very coarse sand, CS= coarse sand, MS= medium sand FS= fine sand, VFS= very fine sand, C=Clay).

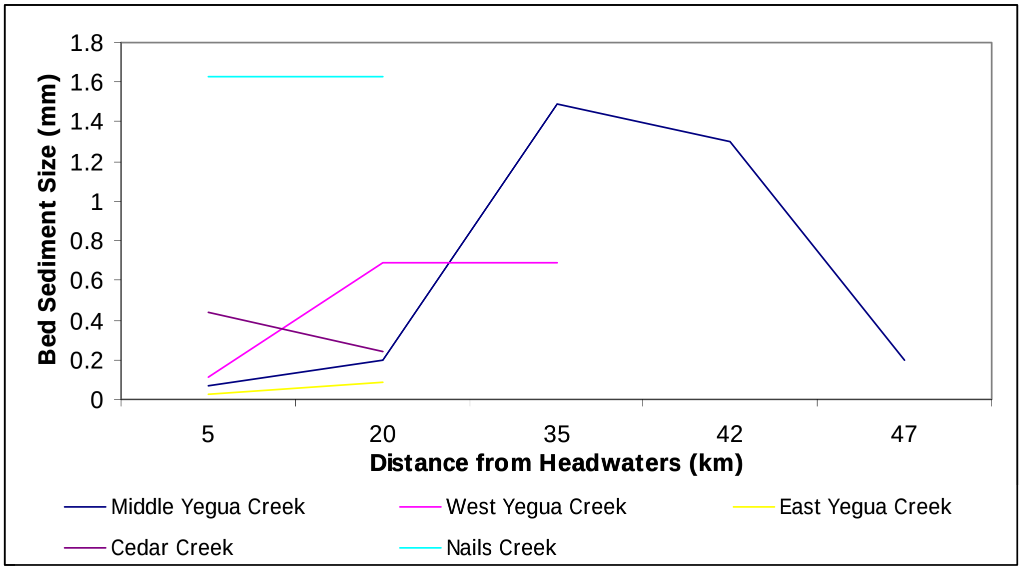

Fig. 31. Median sediment size distributions upstream of Somerville Dam.

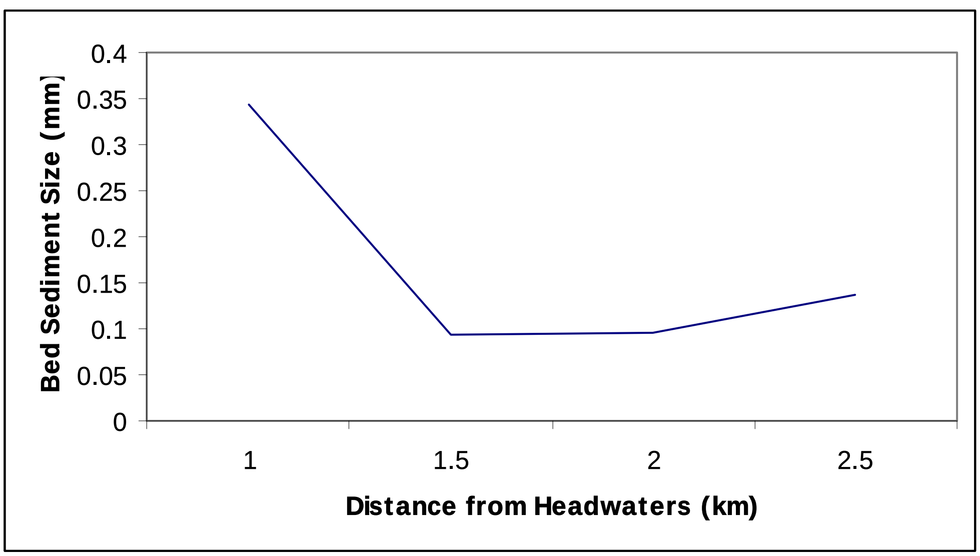

Fig. 32. Davidson Creek median sediment size distribution.

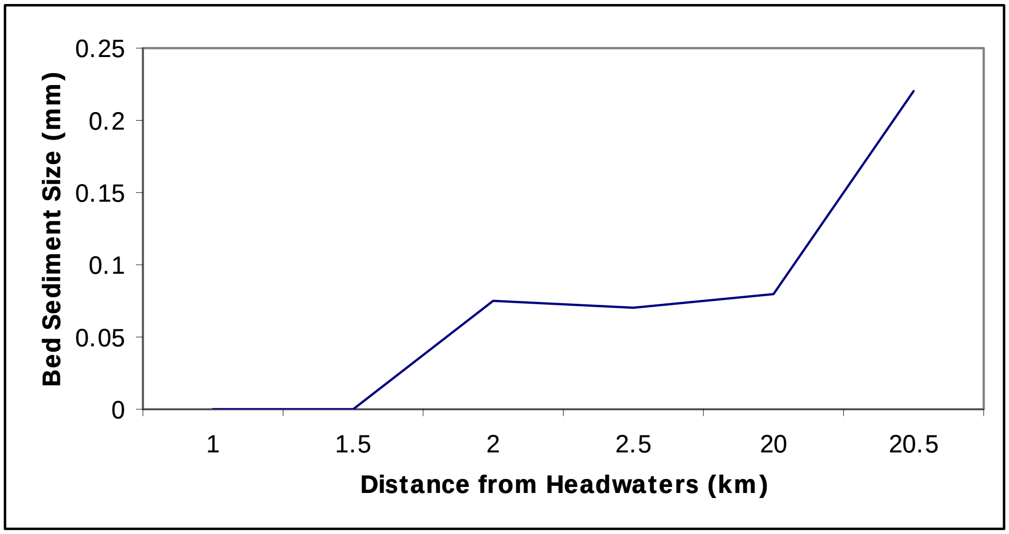

Fig. 33. Yegua Creek sediment size distribution downstream of Somerville Dam.

(Fig. 28). With distance downstream, Davidson exhibits a decrease in median sediment size (Fig. 32). Coarse sediment size average on Davidson Creek is 1.25 mm and ranges from 0.30 mm to 2 mm (Fig. 29). These are classified as very coarse sand to medium sand (Fig. 30). Davidson Creek showed a decrease in sediment size with distance from headwaters (Fig. 32).

Main Yegua Creek downstream of Somerville Dam had an average of 0.07 mm median sized sediment. These values ranged from 0.000625 mm to 0.22 mm (Fig. 27) and are classified as clay to fine sands (Fig. 28). Furthermore, coarse sediment size analysis reveals an average 0.17 mm which ranges from 0.04 mm to 0.43 mm (Fig. 29). These are classified as medium sands to silts (Fig. 30). Yegua Creek also showed an increase in median sediment size with distance downstream (Fig. 33).

In addition, skewness and kurtosis were calculated to determine the spread and size concentration of bed sediment. To calculate skewness (equation 7) and kurtosis (equation 8) sediment size diameter values were converted to phi values (equation 6, Table 7). Skewness calculations show a concentration of sediment towards mostly fine and fine throughout the basin. Two exceptions are Davidson Creek just before its confluence with Yegua Creek and upper Cedar Creek south of Lake Somerville (Table 8). More specifically, East Yegua Creek and Middle Yegua Creek are skewed more heavily towards fine sediment. There is also a wider range of skewness along Davidson Creek, Cedar Creek and Nails Creek.

Table 7.
Cumulative particle size phi (ϕ) values (Cross Section abbreviations refer to those found on Table 3).

Cross Section	Phi Values phi50	phi84	phi16	phi90	phi10	phi75	phi25
D377	1.54	-1.00	3.54	-1.00	3.74	-0.93	3.47
D161	3.41	0.54	9.38	-0.75	11.70	2.23	4.72
D60	3.40	1.74	4.84	1.42	7.97	2.64	4.32
D1361	2.86	-1.00	4.64	-1.00	4.84	-0.58	0.29
EY413	5.51	2.40	16.61	2.00	13.29	3.07	9.38
EY21	0.29	2.56	4.64	2.11	16.61	2.89	6.27
WY108	3.20	-0.81	7.97	-1.00	16.61	3.47	4.84
WY77	0.54	-1.00	3.18	-1.00	3.64	-1.00	2.40
WY114	0.54	-1.00	2.51	-1.00	3.47	-1.00	2.06
N119	-0.70	-1.00	2.79	-1.00	3.64	-1.00	1.68
C131	1.19	-1.00	2.40	-1.00	3.12	-0.70	2.18
C1697	2.06	0.68	3.49	0.42	3.74	1.25	3.12
MY306	3.86	2.32	9.97	1.74	16.61	2.86	7.16
MY696	2.32	1.60	3.47	1.60	3.64	1.79	3.06
MY21	-0.58	-1.00	2.56	-1.00	3.56	0.15	2.00
MY117	-0.38	-1.00	3.64	-1.00	4.32	-1.00	2.86
MY141	2.32	-0.81	7.38	-0.89	9.38	0.74	3.88
Y36US	10.64	4.56	16.61	3.64	16.61	6.97	16.61
Y36DS	10.64	4.56	16.61	3.64	16.61	6.97	16.61
LA	3.74	2.18	16.61	1.89	16.61	2.47	16.61
LB	3.84	2.79	16.61	2.40	16.61	3.12	10.12
Y50US	3.64	2.86	9.97	2.79	16.61	3.12	5.64
Y50DS	2.18	1.22	6.38	1.00	10.97	1.60	3.47

Table 8.
Cumulative particle size distribution skewness and kurtosis calculations (Cross Section abbreviations refer to those found on Table 3).

Cross section Location	Standard Deviation	Mean	Skewness	Kurtosis
D377	2.27	1.27	0.10	0.57
D161	4.42	4.96	-0.34	2.64
D60	1.55	3.29	-0.16	2.05
D1361	2.82	1.82	0.35	3.53
EY413	7.11	9.50	-0.47	0.94
EY21	1.04	3.60	-2.21	2.26
WY108	4.39	3.58	-0.31	6.80
WY77	2.09	1.09	-0.30	0.72
WY114	1.76	0.76	-0.22	0.77
N119	1.89	0.89	-0.86	0.91
C131	1.70	0.70	0.18	0.75
C1697	1.41	2.08	-0.01	0.94
MY306	3.82	6.14	-0.66	1.82
MY696	0.94	2.54	-0.26	0.85
MY21	1.78	0.78	-0.79	1.30
MY117	2.32	1.32	-0.75	0.73
MY141	4.09	3.29	-0.31	1.72
Y36US	6.03	10.58	0.04	0.71
Y36DS	6.03	10.58	0.04	0.71
LA	7.21	9.40	-0.77	0.55
LB	6.91	9.70	-0.82	1.07
Y50US	3.55	6.41	-0.83	2.88
Y50DS	2.58	3.80	-0.69	2.80

Kurtosis values show a wide variety of concentrations throughout the drainage basin (Table 8). Sediment sizes are concentrated in the median values along Middle Yegua Creek, Davidson Creek, East Yegua Creek and West Yegua Creek. Nails and Cedar exhibit a wider range of values. A wide range of sediment sizes characterizes the area of Yegua Creek immediately below the dam. Downstream of the dam, values concentrate around the mean.

Suspended Sediment

West Yegua Creek, a tributary of Middle Yegua Creek has an average suspended sediment concentration of 8.28 ppm and ranges from 6.32 ppm to 9.28 ppm at low flows (Fig. 34). The suspended sediment of Middle Yegua Creek upstream of the dam averages 14.82 ppm and ranges from 7.87 ppm to 23.21 ppm (Fig. 34). East Yegua Creek averages 10.46 ppm with a range from 5.59 ppm to 15.23 ppm in suspended sediment concentration. Nails Creek, and Cedar Creek average suspended sediment concentrations are 10.21 ppm and 10.00 ppm, respectively. Furthermore, Cedar Creek's suspended sediment concentration ranges from 9.90 ppm to 10.09 ppm (Fig. 34). Trends with distance downstream are displayed in Fig. 35-37. While sediment concentrations are variable, a trend is detected whereby concentrations decreased with distance from headwaters.

Suspended sediment concentrations occurring at high flows upstream of Somerville Dam were 37.00 ppm on Middle Yegua Creek before the West Yegua confluence (Fig. 38). Downstream of the West Yegua Creek confluence, suspended

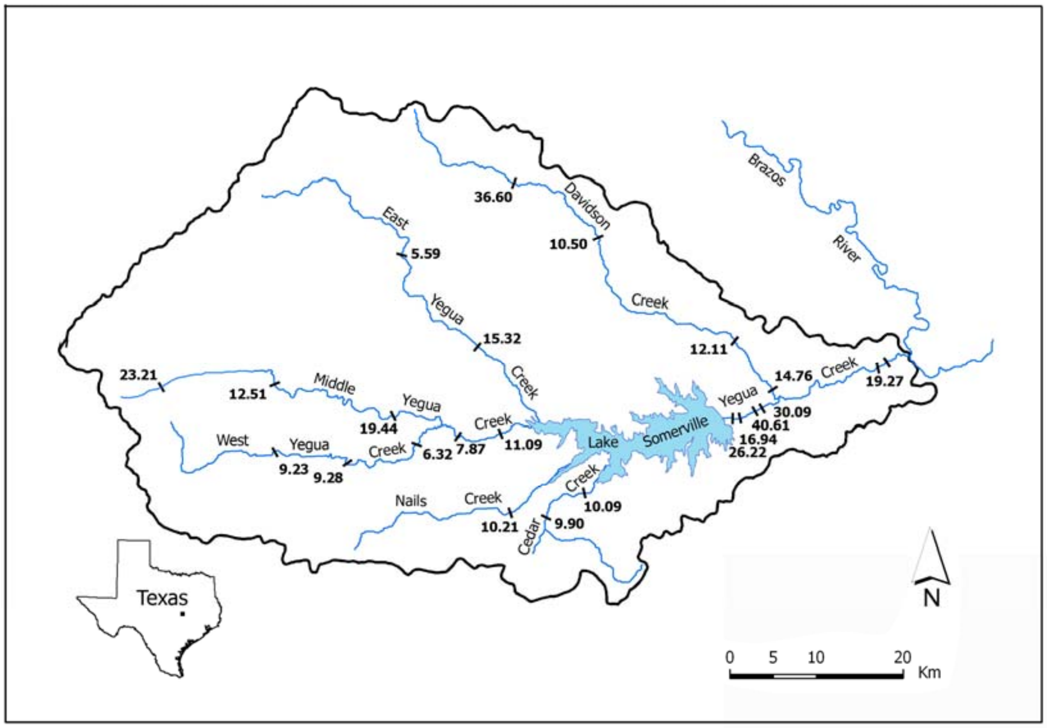

Fig. 34. Low flow suspended sediment concentrations.

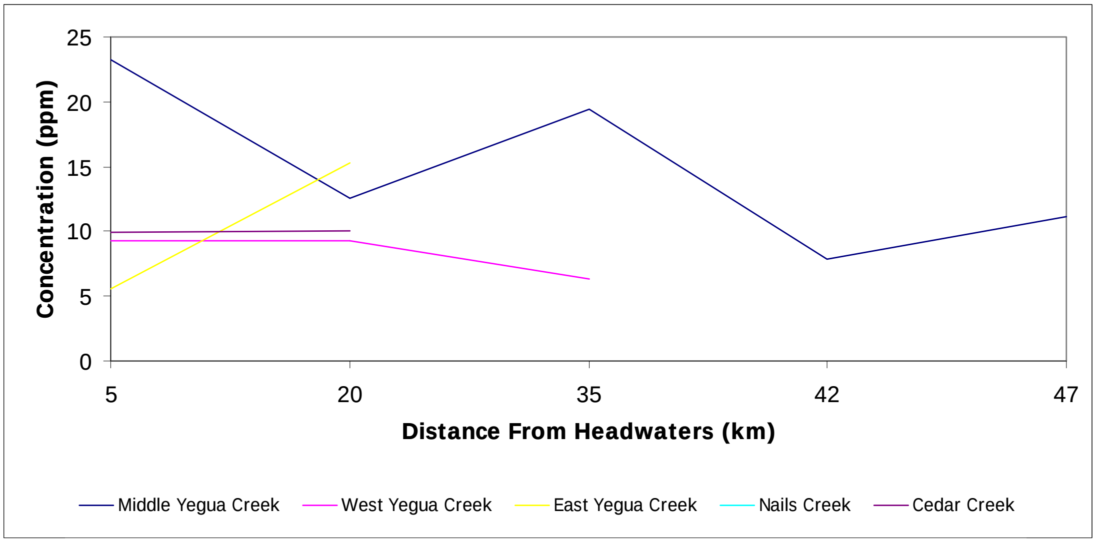

Fig. 35. Suspended sediment concentrations upstream of Somerville Dam.

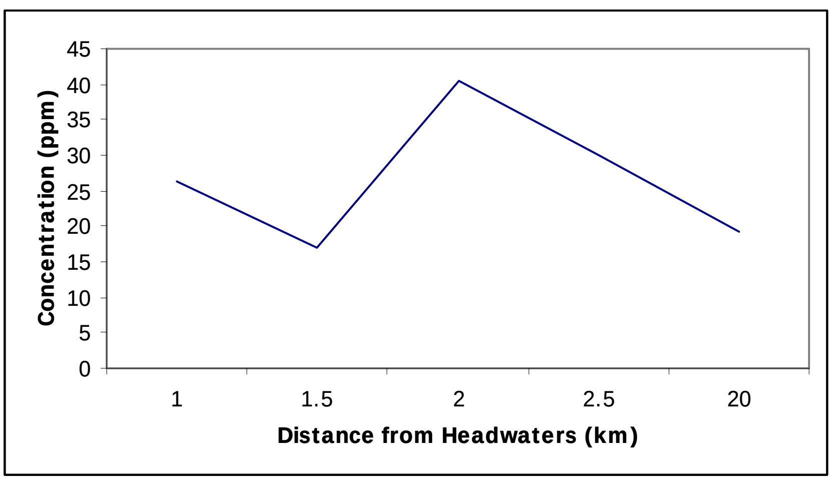

Fig. 36. Yegua Creek suspended sediment concentrations downstream of Somerville Dam.

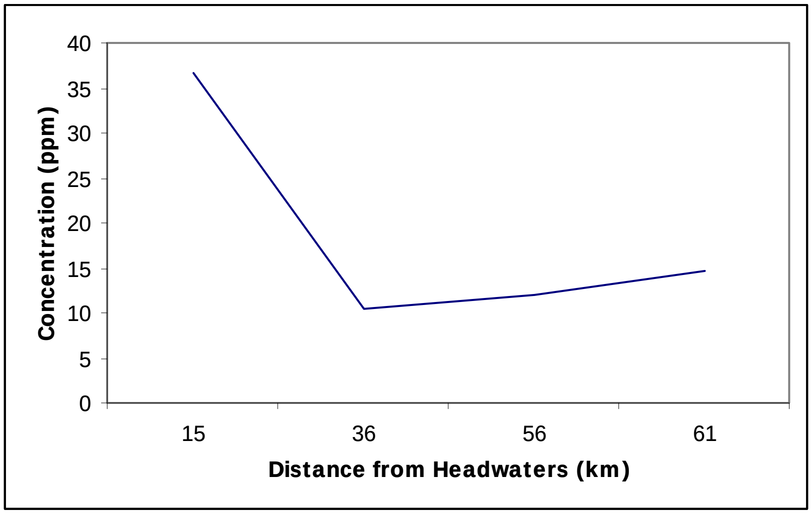

Fig. 37. Davidson Creek suspended sediment concentrations
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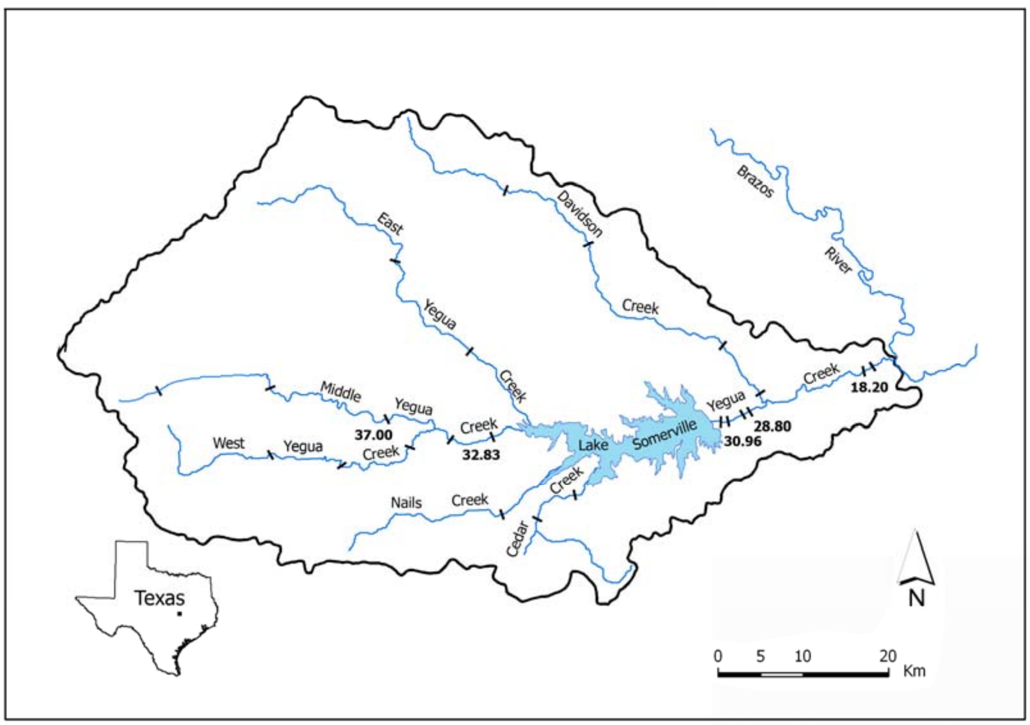

Fig. 38. High flow suspended sediment concentration.

sediment concentration was 32.83 ppm. Downstream of the dam, concentrations averaged 25.99 ppm. These concentrations ranged from 18.20 ppm to 30.96 ppm (Fig. 38).

Sediment Movement Through Somerville Dam

The trap efficiency is the percentage of sediment deposited and trapped by a reservoir (Verstraeten and Poesen, 2000). Using catchment area and reservoir capacity, the trap efficiency of Somerville Dam was determined to be 99.8% based on Equation 2. Therefore, 99.8% of the sediment that enters Lake Somerville is deposited and presumably, does not pass through the dam.

Lake volume changes, assumed to be a result of sedimentation, can also give insight into basin sediment yield (Phillips, 2003). According to the Texas Water Development Board (TWDB), Lake Somerville has lost a total of 7543.6 acre feet of water volume to sedimentation over the nine year period between reservoir surveys (Fig. 39). Taking into account the drainage area of 2,605.44 km^2, as well as the total volume loss between the years of 1995 and 2003, a total of 396.8 $m^3/km^2/yr$ of sediment yield has been deposited into the lake. Therefore, approximately 400 $m^3/km^2/yr$ of sediment is deposited into Lake Somerville.

According to TWDB, the loss in water volume in Lake Somerville is a 3.2% decrease in storage capacity since the last survey (1967) conducted (TWDB, 2005). In addition, sediment storage prior to dam construction was estimated at 16,200 acre feet in 50 years. Water volume loss based on surveying, however, show a substantial amount of

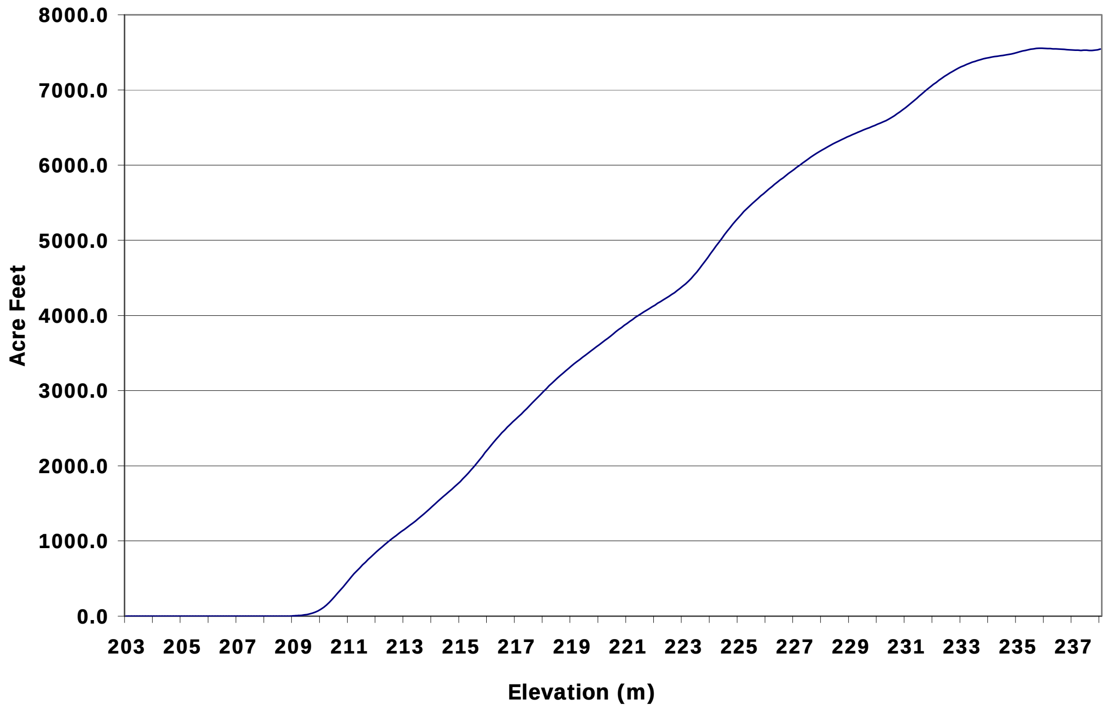

Fig. 39. Cumulative water volume loss in Lake Somerville between 1995 and 2003.

sedimentation. Sedimentation has resulted in a 7,543 ac ft of water volume loss in Lake Somerville between 1995 and 2003. In addition, a previous survey on Lake Somerville reported in Phillips et al. (2004) a 50,538 ac ft loss in water volume due to sedimentation between 1967 and 1995. Combined, these yield an average of 1,570 ac ft loss each year. This loss, in addition to projected average loss for the next ten years yields a 78,489 ac ft loss to sedimentation in 50 years of impoundment. This is much greater than the 16,200 acre feet predicted (USACE, 2007a). Therefore, sedimentation is occurring at a much higher rate than anticipated by the USACE when the dam was constructed.

Sediment Movement Downstream of Somerville Dam

Calculations using the Shield's equation (equation 9) for median (d_{50}) sediment sizes yield the shear stress required to mobilize present sediment (Table 9). The average shear stress needed to move the current sediment present in channel reaches downstream of the dam is 0.0673 N/m^2. Shear stress values range from 0.0006 N/m^2 to 0.1992 N/m^2 to move particles 0.000625 mm and 0.22 mm, respectively. These particles are located at Y36US (Fig. 19) just downstream of the dam and near Yegua Creek's confluence with the Brazos River at the Y50DS cross section (Fig. 19). Particle size and the shear stress required to mobilize these particles increased with distance from the dam.

Shear stress required to mobilize coarse sediment sizes (d_{84}) downstream of Somerville Dam averaged 0.1536 N/m^2 and ranged from 0.0385 N/m^2 to 0.3894 N/m^2. These occurred at the Y36US cross section with 0.0425 mm and the Y50DS cross section with 0.43 mm in sediment size, respectively (Table 10). Particle size and the

Table 9.
Shear stresses required for movement of median sediment sizes (Cross sections refer to those listed in Table 3).

Cross Section	Particle Size (mm)	Particle Size Category	Critical Shear Stress N/m2
Y36US	0.000625	Clay	0.0006
Y36DS	0.000625	Clay	0.0006
LA	0.075	Very fine sand	0.0679
LB	0.07	Very fine sand	0.0634
Y50US	0.08	Very fine sand	0.0724
Y50DS	0.22	Fine sand	0.1992

Table 10.
Shear stresses required for movement of coarse (84^{th} percentile) sediment sizes (Cross sections refer to those listed in Table 3).

Cross Section	Particle Size (mm)	Particle Size Category	Critical Shear Stress N/m2
Y36US	0.0425	Silt	0.0385
Y36DS	0.0425	Silt	0.0385
LA	0.22	Fine sand	0.1992
LB	0.145	Fine sand	0.1313
Y50US	0.1375	Fine sand	0.1245
Y50DS	0.43	Medium Sand	0.3894

shear stress required to mobilize these particles increased with distance from the dam as well.

In addition, flow records acquired from USGS gaging station 08110000 (Fig. 5) for the period of record (1967 -1992) provided insight into sediment movement after stream impoundment. The stage heights reported in the discharge data associated with these flows enabled the shear stress to be determined. (Equation 10, Appendix A). These were then compared against the critical shear stress needed to entrain the sediment present downstream of Somerville Dam (Tables 9 and 10).

The results show that both median and coarse sediment sizes were mobilized by the majority of the flows recorded after stream impoundment (Appendix A). The check marks in the appendix indicate the events when the shear stress produced by that flow exceeded critical stream stresses required for entrainment. Thus, the flows were capable of mobilizing sediment most of the time. Because sediment sizes in both the median and coarse categories increased with distance from the dam, the critical shear stress required to mobilize sediment increased downstream as well. Therefore, instances where stage height and its respective stress was not capable of moving the present sediment occurred more often at sites located farther from Somerville Dam. These instances are depicted in Appendix A where blanks are located. In all, median and coarse sediment sizes were mobilized almost all of the times stage height was measured after stream impoundment between 1967 and 1992.

Observations from Aerial Photographs

Aerial photos of Yegua Creek from 1995 and 2003 provided qualitative information regarding depositional features downstream of Somerville Dam. Because of differing aerial photograph resolutions and stage heights however, quantitative comparisons regarding the size and distribution of depositional features were not reliable ultimately. Table 11 presents the stage heights at the time aerial photographs were taken. The gage heights for 1995 and 2004 occurred after the discontinuation of gaging station 08110000 (Fig. 5). Therefore the gage heights for Davidson Creek, a major tributary of Yegua Creek downstream of Somerville Dam, were used.

One example of digitizing is illustrated in Figure 40. The sand bar is digitized as a polygon in 1988, 1995 and 2004. Flooding is apparent in the 1958 photograph and stage height is substantially lower in 2004. The increase in sand bar size in 2004 is likely due to the decreased stage height, making more of the sand bar visible in this photograph. In addition, the low resolution of the 1958 and 1988 photographs make digitizing difficult for this period of time.

Qualitative analysis of aerial photographs give indication of erosional and depositional processes and features downstream of Somerville Dam. Immediately downstream its confluence with Wolf Creek, 5.5 km downstream of Somerville Dam (Fig. 19), Yegua Creek developed some depositional features that remain evident until its confluence with the Brazos River (Fig. 41). The most prominent appearance of these depositional features occurred in 2004 where stage height was substantially lower than

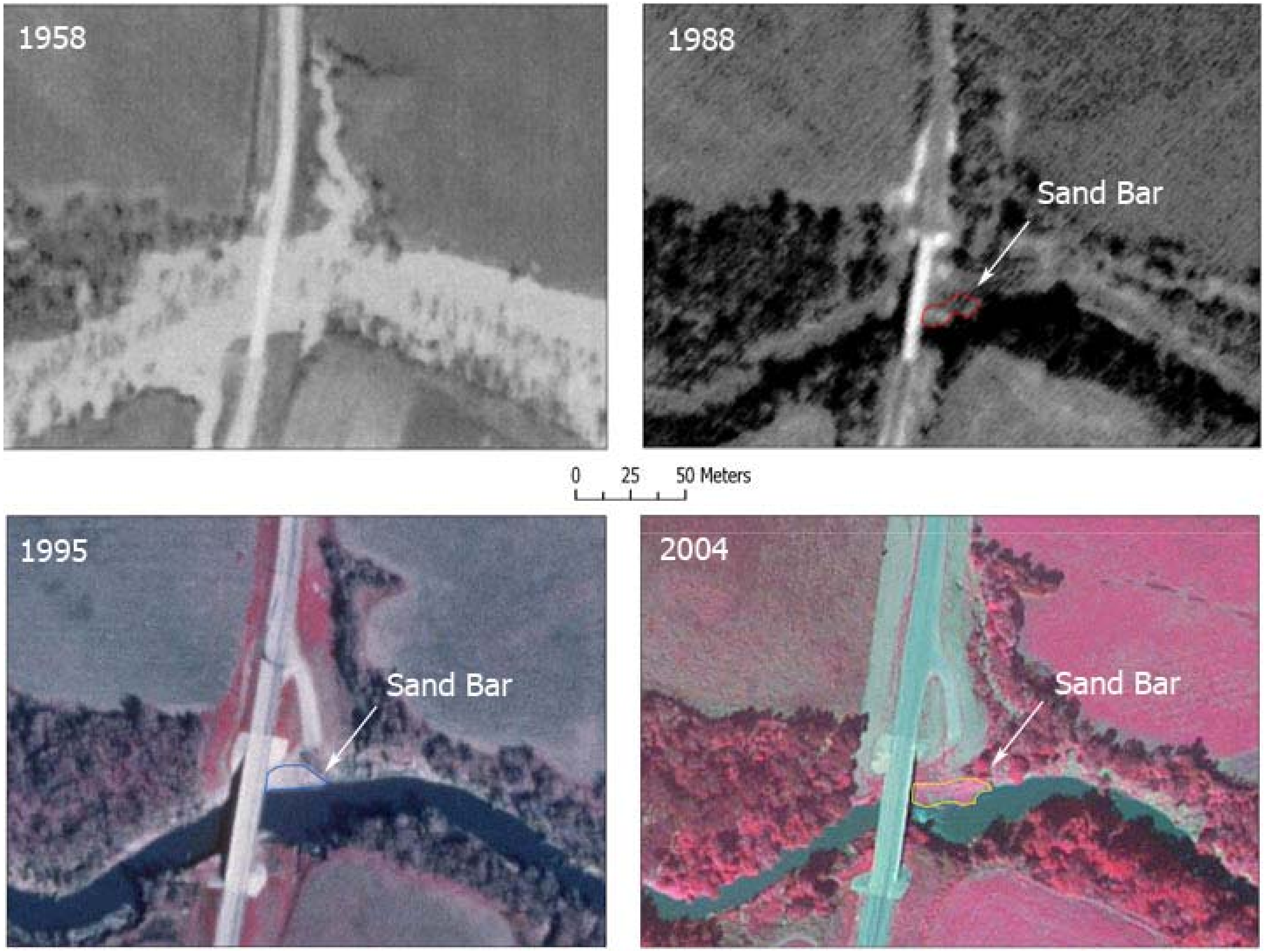

Fig. 40 Methods figure.

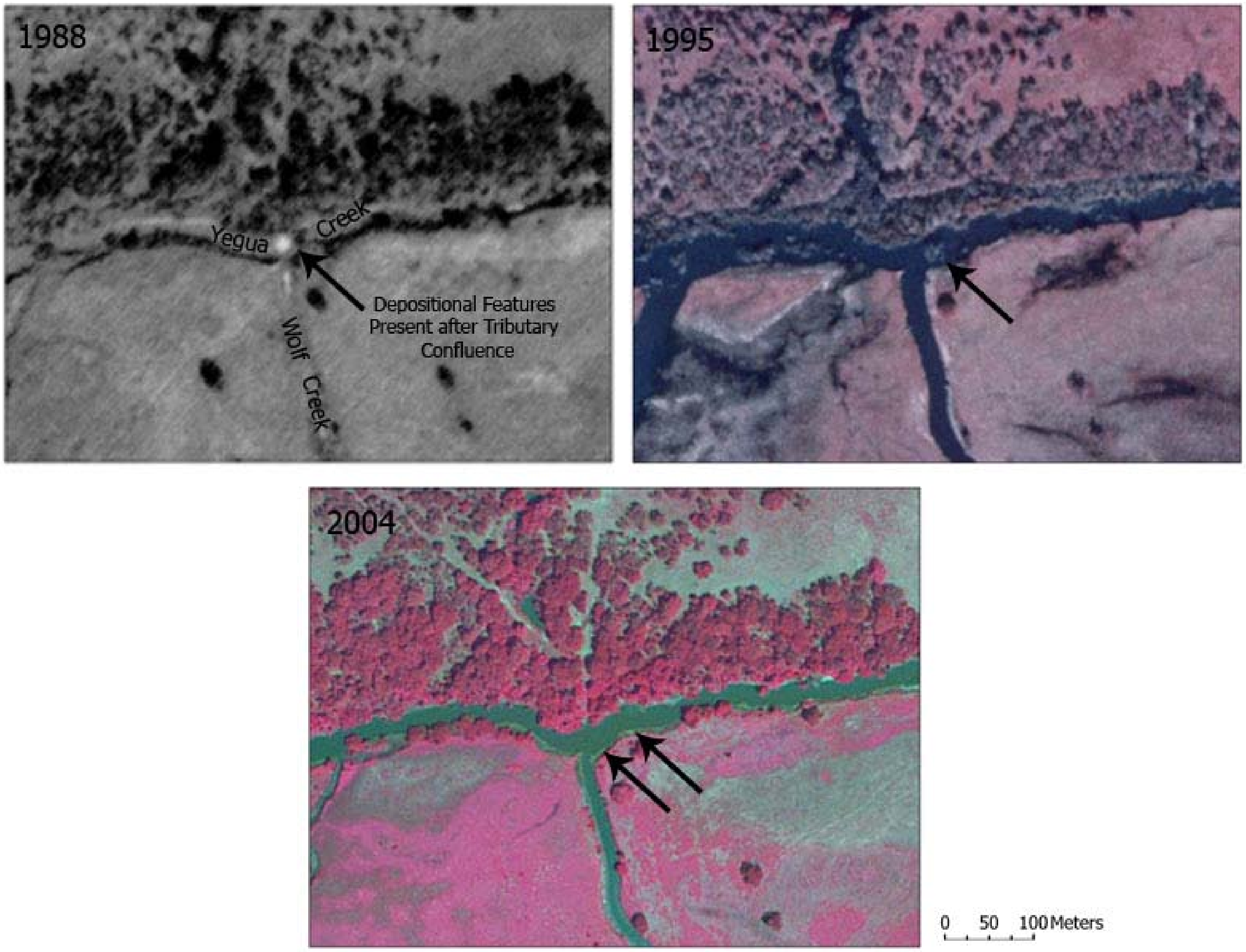

Fig. 41. Yegua Creek depositional features at the Wolf Creek confluence (Fig. 19).

Table 11.
Gage heights for corresponding aerial photographs. Asterisk (*) denotes gage height from Davidson Creek.

Date	**Yegua Creek Gage Height (m)**	**Davidson Creek Gage Height (m)**
February 28, 1958	1.285	Not Available
January 17, 1988	0.18	0.72
January 17-March 6, 1995	Not Available	2.21*
July 27- September 7, 2004	Not Available	0.72*

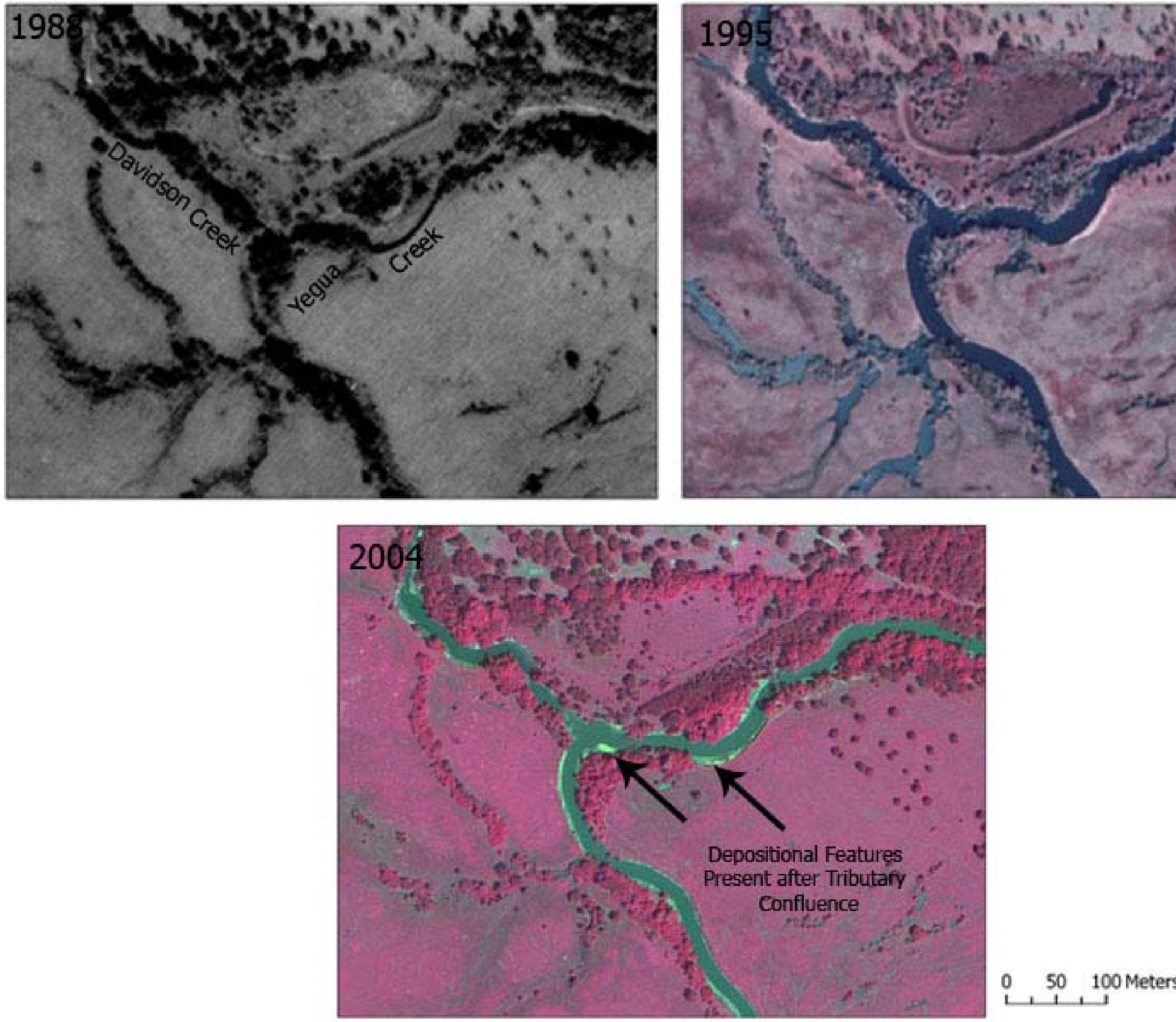

Fig. 42. Yegua Creek depositional features at the Davidson Creek confluence (Fig. 19).

in previous years (Table 11). This increase in depositional features was also evident near Davidson Creek's confluence (Fig. 42) in the 2004 photograph, although more depositional features may be visible in 2004 due to a lower stage height. In addition, the low resolution of the 1988 image near Davidson Creek makes it difficult to see depositional features present at that time.

Qualitative analysis of the 2004 aerial photograph shows active deposition and erosion occurring downstream of Somerville Dam. Fig. 43, located 355 m upstream of Davidson Creek (Fig. 19), clearly shows areas of significant deposition and erosion along several Yegua Creek meanders. Fig. 44, 3.3 km upstream Y50US (Fig. 19), indicates erosion and deposition as well. The actively developing depositional bar is noted on the far right meander, accompanied by erosion on the opposite bank. The same is true for the meander in the top left of the figure.

Field observations corroborate evidence of deposition and erosion provided by the aerial photographs. Figures 45 and 46 show the same location (Y50DS, Fig. 19), before and after a summer of 2007 flood event. Fig. 45 clearly shows a sand bar on the left edge of water. After a flood event, the absence of the sand bar is clear. This location is depicted in Fig. 47 as an aerial photograph. The sand bar is the depositional feature found in Fig. 45. In addition, the unstable bank showing active erosion is the feature depicted in Fig. 17. Therefore, aerial photographs and field observations support the conclusion that Yegua Creek is actively eroding and depositing sediment downstream of Somerville Dam and is not dominated by one single process regime.

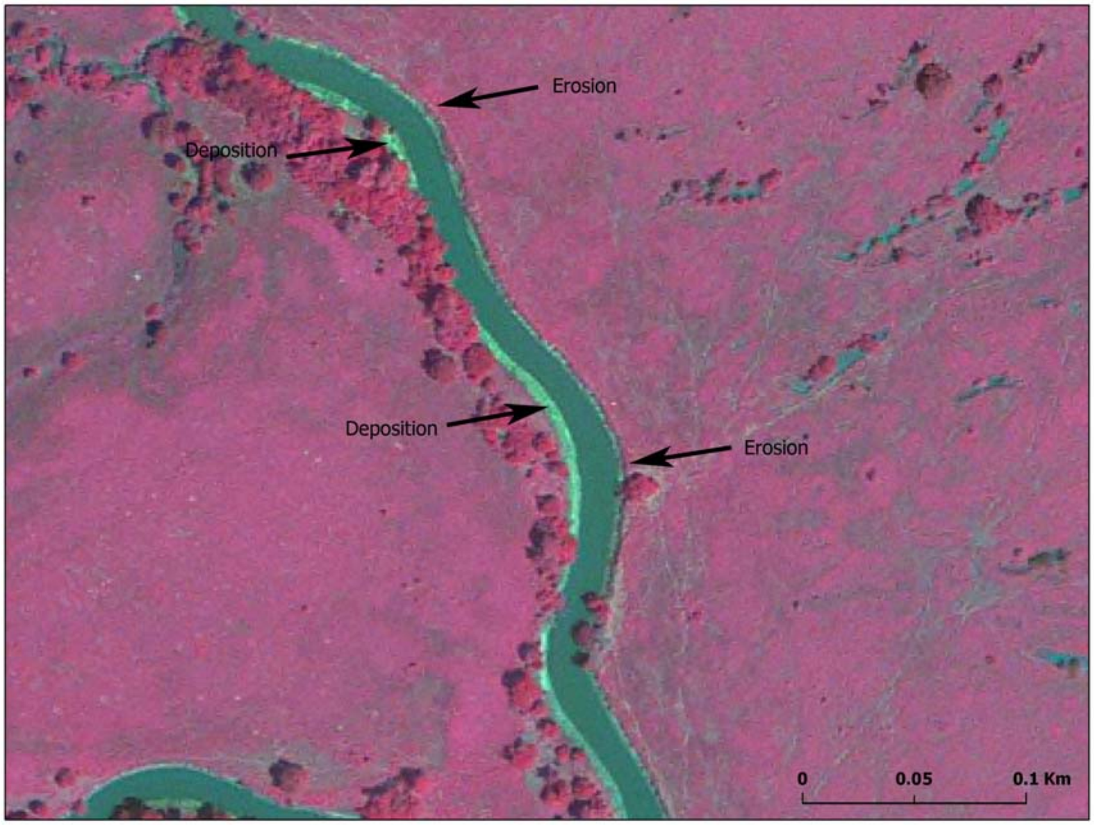

Fig. 43. Depositional and erosional features downstream of Somerville Dam.

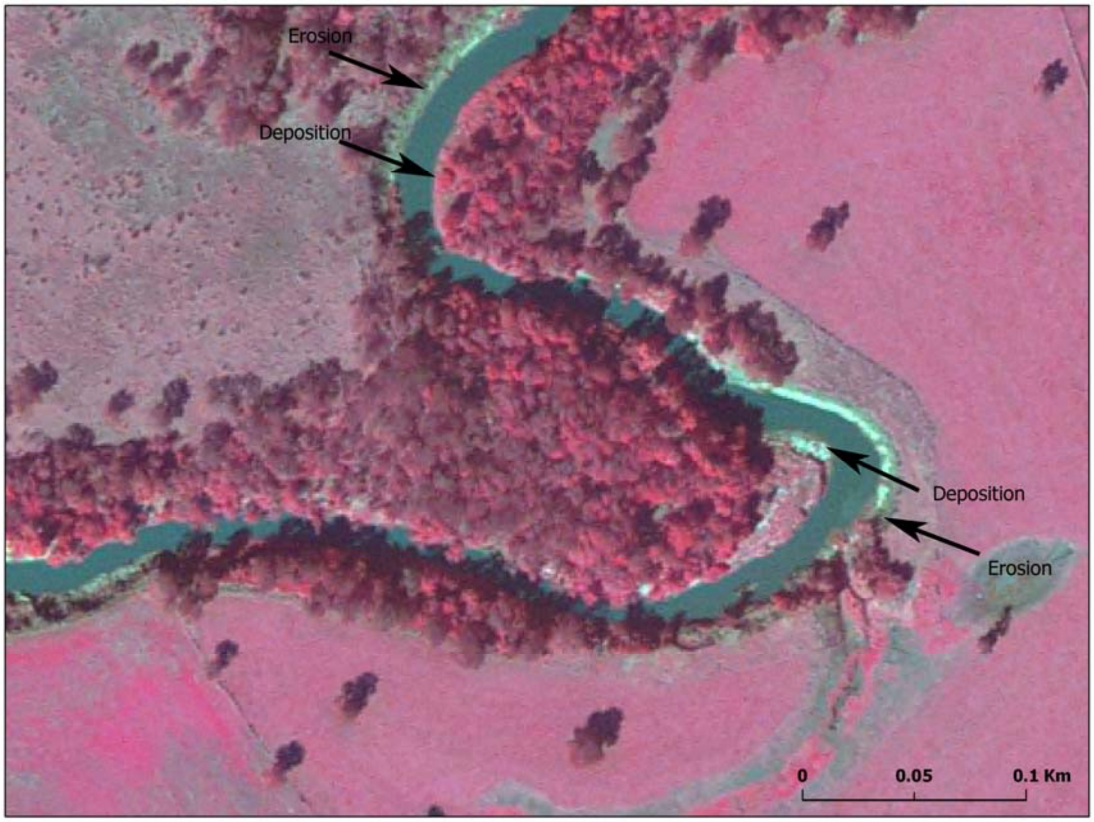

Fig. 44. Depositional and erosional features upstream of Y50US (Fig. 19).

Fig. 45. Yegua Creek depositional feature downstream of Somerville Dam.

Fig. 46. Same location on Yegua Creek after major flood event. Note absence of depositional feature.

Fig. 47. Y50US cross section.

CHAPTER VI

DISCUSSION AND CONCLUSIONS

Discussion

Sediment Characteristics

Although much variability is expected, undisturbed stream reaches typically show a decrease instead in median (d_{50}) and coarse (d_{84}) sediment sizes with increasing distance downstream (Graf, 1980; Chien, 1985; Knighton, 1987). For example, The Aya River and the Colorado River both exhibited a decrease in particle size with distance from Huchu Dam and Hoover Dam, respectively (Williams and Wolman, 1984). Davidson Creek, Cedar Creek, and Middle Yegua Creek downstream of its confluence with West Yegua Creek exhibited this expected decrease in median sediment sizes (Figures 29 and 30). In addition, Cedar Creek and East Yegua Creek showed a decrease in the coarser (d_{84}) sediment sizes with distance downstream. These trends are consistent with those of most natural streams.

This trend was not found on Yegua Creek below Somerville Dam, however. Downstream of Somerville Dam, Yegua Creek experiences an increase in sediment size with distance from the dam (Fig. 31), unlike the decrease found in previous studies on impounded streams. The absence of this phenomenon can be attributed to the characteristics of this particular basin, in which most of the tributaries upstream of Lake Somerville experienced a coarsening with distance from it's headwaters. This is likely due to an increase in discharge with increase catchment area common in most basins that transports fine sediment and deposits coarser sediment. East Yegua, Middle Yegua, and West Yegua Creek showed significant coarsening in median sediment sizes with distance downstream as well.

The soil surveys of Washington County (southeast of Lake Somerville) and Lee County (west of Lake Somerville) show Kaufman soils, primarily consisting of clay and loam, surrounding Yegua Creek and all of its tributaries. However, these Kaufman soils are surrounded by fine sandy loam soils and loamy sand above Somerville Dam, whereas Kaufman soils are surrounded by excessively fine, clayey soils downstream of the dam (Burgess and Lyman, 1906; Chervenka et al., 1981). These characteristics may explain the concentration of coarse materials upstream of the dam, as well as their absence downstream of the dam.

Changes in sediment characteristics over time can also occur after stream impoundment. In some instances, coarsening can occur downstream of a dam. This coarsening can appear due to the "hungry water" effect immediately downstream of the dam that carries away fine sediment, leaving coarse sediment behind (Kondolf, 1997). On the other hand, some research suggests a decrease in median sediment sizes directly downstream of impoundments over time. This can be a result of fine sediment supplied from upstream of the impoundment, tributary sediment contributions, or the exposure of fine sediments due to channel scouring (Williams and Wolman, 1984). Specifically, locations immediately downstream of Hoover Dam on the Colorado experienced a decrease in sediment size after impoundment (Williams and Wolman, 1984).

Initial coarsening can reverse to fining of sediment downstream of an impoundment after some time. Studies on the Missouri River downstream of Gavins Point Dam and the Colorado River downstream of Davis and Parker Dams show an initial increase in median sediment sizes before stabilizing 1-10 years after impoundment (Williams and Wolman, 1984). This reversal of sediment coarsening is less likely to propagate with increasing distance from the dam (Williams and Wolman, 1984). A similar reversal trend evident along the Colorado occurred 1.1 km downstream of Davis Dam and 26 km downstream of Parker Dam where sediment decreased in size approximately 10 and 30 years after impoundment, respectively (Williams and Wolman, 1984). Forty years after impoundment, the same could be true downstream of Somerville Dam.

Sediment Movement through Somerville Dam

The 99.8% trap efficiency of Somerville Dam is higher than the 81% found at the nearby Livingston Dam on the Trinity River (Phillips et al., 2005). However, Williams and Wolman reported an average of approximately 99% for large reservoirs (1984). In addition, Canton Dam in Oklahoma has a trap efficiency of 99.5% and Denison Dam on the Red River (Texas and Oklahoma) traps 99.2% of sediment. Therefore, Somerville Dam has a trap efficiency similar to large impoundments and those in east Texas.

Sediment yield for Somerville Dam, approximately 396.8 $m^3/km^2/yr$, is similar to other Texas impoundments. According to Phillips et al. (2004), the average sediment yields for impoundments is 284.9 $m^3/km^2/yr$ and can range from 5.8 $m^3/km^2/yr$, found at

Lake Houston to 1002.7 $m^3/km^2/yr$ at Lake Aquilla. Phillips et al. (2004) estimated the sediment yield of Lake Somerville at 853.7 $m^3/km^2/yr$ in the previous sediment survey conducted between 1967 and 1995, which represents a 28 year span. One reason to explain differences in sediment yields concerning the 1967-1995 and 1995-2003 surveys is the likelihood of higher magnitude floods present in the survey conducted within a longer time span (Phillips et al., 2004). These sediment yields give insight into the amount of sediment trapped by their respective dams. If trap efficiency is not overestimated, the majority of this sediment is not passing through Somerville Dam. However, varying sediment characteristics over time and differences in release patterns can alter the sediment trap efficiency over time. Overestimation is unlikely based on reservoir surveys which determined sedimentation.

Furthermore, sediment storage exceeds that planned for Somerville Dam prior to impoundment. The life expectancy, therefore, could be shorter than estimated. Problems associated with decreasing storage capacity, including limitations in water storage, could occur sooner than expected. If so, Somerville Dam will no longer have the ability to serve its original purpose.

Finally, sediment trapping by the dam may have caused a “decoupling” of the upper and lower basin on Yegua Creek, similar to the Trinity River (Phillips et al., 2004). This decoupling could prevent sediment interaction between the upper and lower basin, creating sediment characteristics independent of each other.

<u>Movement of Bed Sediment Downstream of Somerville Dam</u>

According to the theoretical calculations of entrainment based on Shield's equation presented in the previous chapter, median sediment downstream of Somerville Dam is capable of mobilization during the majority of the flows recorded after stream impoundment (Appendix A). In addition, coarse (d_{84}) sediment sizes are also capable of being mobilized after impoundment (Appendix A). However, some possible sources of error are included in these calculations. For instance, sediment was sampled in the 2007 and the latest flow data was recorded in 1991. Any changes in flows ability to transport sediment after 1991 are not reflected in the results.

Theoretical transport calculations are highly dependent on the Shield's parameter (φ) which quantifies imbrication. The value used in this study, 0.056, may underestimate imbrication. In addition, Wilcock and McArdell (1993) found that the stream power calculated to transport sediment can be as little as half the actual power required to move sediments of a specific size in their environment (Elliot and Parker, 1997).

These results corroborate field observations. Figures 45 and 46 how Yegua Creek near its confluence with the Brazos River (Y50DS, Fig. 18 Table 2). Figure 44 shows the creek prior to a flooding event. Note the sand bar located on the left edge of water. Figure 45 is this same location after a flood event. During this June 2007 flood event, dam gates were opened 3 feet, releasing an average of 1,119.1 cfs from the dam (USACE, 2007b). Average discharge released from the dam in 2007 was 568 cfs and ranged from 2 cfs to 1638 cfs. The absence of the sand bar is clear after the flood event. Therefore, current discharges are capable of transporting sediment.

Complete mobilization of sediment is unlikely however, due to vegetated banks along stream channels. Riparian vegetation has been found to decrease erosion and increase sedimentation (Elliot and Parker, 1997; Friedman et al., 1998; Gordon and Meentemeyer, 2006). Other studies conducted on reaches downstream of impoundments have found an increase in riparian vegetation along banks, likely resulting from a decrease in peak flows that would normally discourage vegetation establishment (Elliot and Parker, 1997; Gordon and Meentemeyer, 2006).

For example, decreased peak flows encouraged sediment deposition and the establishment of vegetation on the Gunnison River (Elliot and Parker, 1997). Jennings (1999) reported a similar situation along Yegua Creek in which riparian vegetation along the stream banks increased 25% in the 20 year study period due to decreased peak discharges which now rarely hinder vegetation establishment. This is illustrated in Fig. 48 where vegetation along Yegua Creek's banks underwent significant development between 1958 and 1988, the period in which impoundment began. In addition,

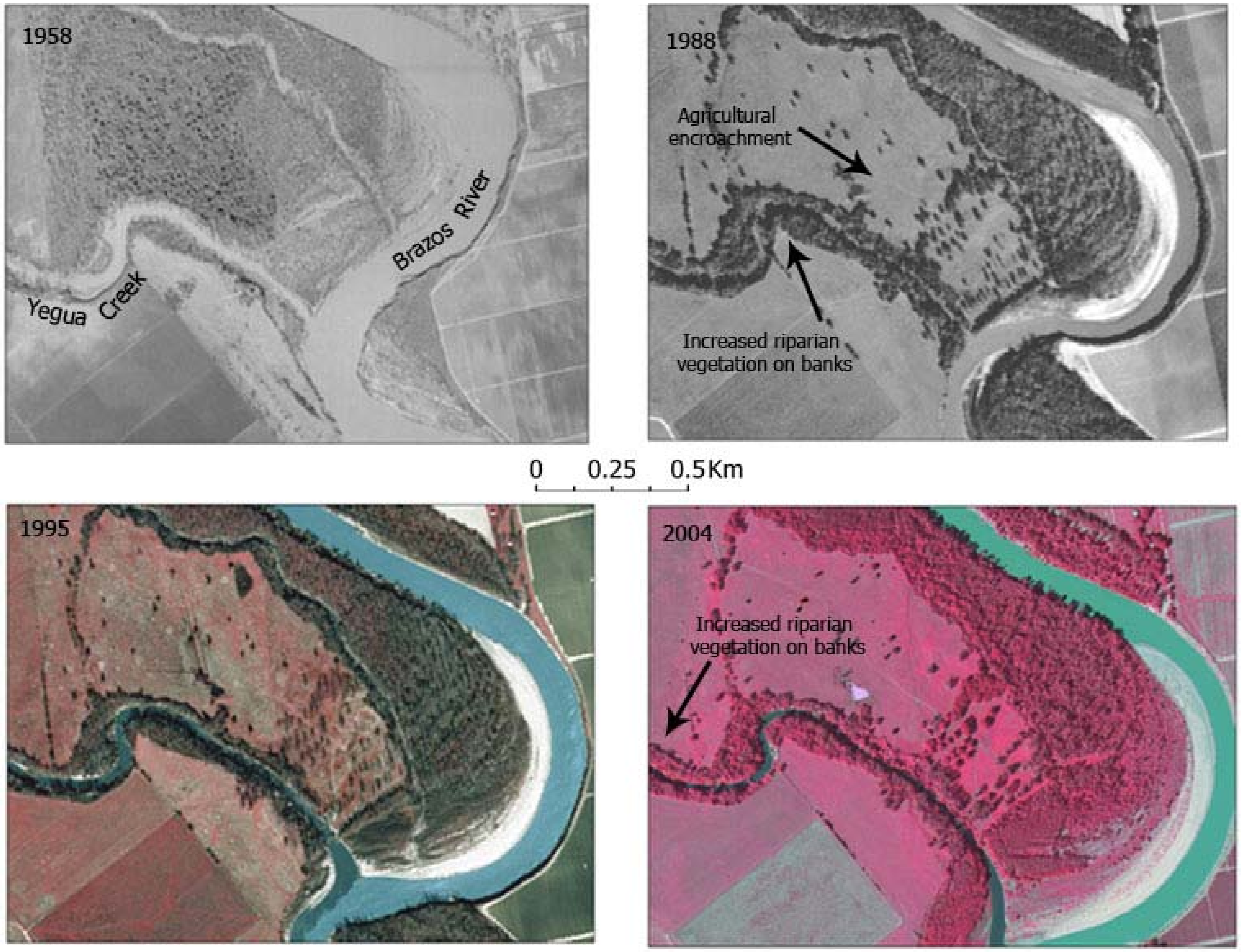

Fig. 48. Riparian vegetation and agricultural development on Yegua Creek near its confluence with the Brazos River.

conditions along Yegua Creek's banks differ from conditions in the surrounding area. The appearance of vegetation in streams is likely to make Shield's calculations unreliable and may account for the overestimation of sediment movement downstream of Somerville Dam (Elliot and Parker, 1997).

Evidence of this phenomenon is found along Yegua Creek as well. Banks at the Highway 36 cross section of Yegua Creek are highly vegetated and unlikely to be erosive (Fig. 14). However, banks along the Landolt cross sections, where suspended sediment is highest, are mostly free of vegetated material (Fig. 15). The lack of vegetation could account for easily erodable banks and therefore, an increase in suspended sediment concentrations.

In addition, tributaries can have a substantial influence on sediment supply in a stream, and therefore depositional features. Elliot and Parker (1997) found that tributaries supplied a great deal of alluvial material in the Gunnison Gorge. In addition, tributaries were found to supply a significant amount of sediment to the River Mersey in Tasmania (Knighton, 1988b) and the Green River, Utah (Grams and Schmidt, 2005). This increase in sediment supply, coupled with a decrease in discharges due to regulation, can cause an increase in depositional features that can no longer be transported by available flows (Kondolf, 1997). This seems to be the case on Yegua Creek where depositional features are evident downstream of the first tributary until its confluence with the Brazos River.

Furthermore, the shear stresses produced by recorded stage heights show a reduction in the ability to entrain sediment present in the lower reaches of Yegua Creek near the Brazos River. This is due to an increase in sediment size with increasing distance from the dam. It is likely that Davidson Creek (Fig. 17), Yegua Creek's major tributary downstream of Somerville Dam provides much of the coarse sediment found downstream of the confluence. The sediment load supplied by this unregulated tributary increases sediment size downstream of its confluence. Shield's calculations then show that flows released from the dam are less capable of transporting this sediment.

However, in addition to sediment supply, Davidson Creek may provide significant stream power because it is an unregulated stream. The absence of a gaging station downstream of Davidson's confluence makes determining the exact stage height between 1967 and 1992 impossible. Therefore, Yegua Creek's stream power with the addition to stream power provided from Davidson Creek may still be capable of transporting available sediment.

Movement of Suspended Sediment Downstream of Somerville Dam

Suspended sediment concentration in an undisturbed basin typically increases with distance downstream and with increasing basin size (Knighton, 1987). In the Yegua Creek drainage basin upstream of Lake Somerville, this is the case for East Yegua Creek, Middle Yegua Creek after its confluence with West Yegua Creek, and Cedar Creek. It is not true for Davidson Creek, Middle Yegua Creek, and West Yegua Creek. Impounded streams can also exhibit a decrease in suspended sediment. For example, Hoover Dam and Glen Canyon Dam decreased the suspended sediment load variability and concentration of the Colorado River due to sediment trapping (Williams and Wolman, 1984).

Yegua Creek downstream of Lake Somerville shows an increase in suspended sediment followed by a decrease. One possible reason is the increased importance of the input of tributaries influencing sediment availability after Yegua Creek's impoundment (Williams and Wolman, 1984). Approximately one half of a kilometer downstream of the Highway 36 cross sections, Wolf creek enters Yegua Creek (Fig. 19, Fig. 41). This input could cause the increase in suspended sediment concentrations at both Landolt (LA and LB) cross sections (Fig. 18, Table 2). Davidson Creek, another tributary of Yegua Creek supplies a substantial amount of suspended sediment concentration and discharge (Fig. 41).

In addition, an adequate amount of sediment may be available downstream of the dam despite sediment trapping. According to Phillips (2003), reworked pre-dam alluvium is a possible source, although unlikely along the Sabine River, Texas. Pre-dam alluvium, therefore could be a sediment source along Yegua Creek.

Suspended sediment concentrations at high flows along Yegua Creek reiterate the finding that sediment is being transported downstream of Somerville Dam. Fig. 49 and 50 show Yegua Creek at high and low flows, respectively. Sediment concentrations

Fig. 49. Yegua Creek during flood event downstream of Somerville Dam.

Fig. 50. Same location after flood event (Note: Sign suffered some damage during event).

averaged 26 ppm downstream of Somerville Dam at high flows. These concentrations occurred at an average discharge of 15.48 cms. Therefore, high flows produced by the dam have the ability to transport sediment.

Therefore, the characteristics observed in the present channel system reflect a system in balance where erosional and depositional processes downstream of the dam are both occurring and not dominated by one regime, as was likely the case during the period of adjustment.

Summary of Findings

Analyses of sediment characteristics upstream and downstream of Somerville Dam permit the following major findings. The bed sediments upstream of Lake Somerville were generally coarser than those found downstream of the dam. Once deposited behind the dam, results of this study show that sediments are unlikely to be transported through the dam to the downstream reaches of Yegua Creek. An increase in sediment size with distance from the dam was also found on Yegua Creek, although this is not typical of most streams. However, tributary inputs, fine sediment supplied from the dam, erosional processes in surrounding areas and local sediment characteristics could account for these differences.

The first objective of this study was to determine to what extent sediment is passing through Somerville Dam. According to Lake Somerville Surveys, 396.8 $m^3/km^2/yr$ is being deposited into the reservoir. Furthermore, the reservoir traps 99.8%, a large majority of this sediment. These results support the working hypothesis that an insignificant quantity of sediment passes through the dam. Thus, the sediment trapping has resulted in disconnecting the upper and lower portions of the Yegua Creek watershed.

The second research objective addressed in this thesis was to determine the extent present flows are mobilizing downstream of Somerville Dam. Suspended sediment measurements show an increase in suspended sediment concentration downstream of Somerville Dam, which is unusual for natural streams.

In addition, analysis of bed sediment characteristics, coupled with theoretical calculations of entrainment, determined sediment mobilization. Median sediment sizes are capable of mobilization by the majority of flows provided by releases from Somerville Dam. However, a decrease in flows with the ability to entrain coarser sediment sizes occurred after dam closure. Therefore, river regulation has decreased coarse (d84) sediment transport capacity in Yegua Creek. The working hypothesis was that the reduction in flood peaks owing to river regulation has decreased sediment transport capacity in Yegua Creek which no longer allows sediment to move downstream of the dam and into the Brazos River. However, little difference in shear stresses before and after impoundment capable of moving present sediment was found in this study.

Ultimately, results regarding suspended sediment concentrations and sediment entrainment, in conjunction with previous findings along Yegua Creek, support the interpretation that Yegua Creek has reached a new equilibrium following impoundment by Somerville Dam. In response to a large decrease in peak flows after impoundment, channel adjustments resulted in a 65% decrease in channel capacity (Chin et al., 2002) was the channels response to the new flow regime. In other words, channels reduced in size as a result of incompetent flows causing deposition within channels. The site reduction occurred primarily in the depth dimensions. After several decades, however, the channel adjustments have apparently produced a new regime that enables sediment transport. This was evidenced in the 9% decrease in channel width and 61% decrease in channel depth (Chin et al., 2002).

Significance

This study provides insight about the interrelationships among the different system components. Previous research has shown that impoundment has caused a decrease in peak flows along Yegua Creek. This, in turn, has caused a reduction in stream capacity because smaller flows no longer had the ability to entrain available sediment. A reduction in channel capacity is consistent with growth of vegetation, which was able to establish along the banks due to a decrease in disturbance by peak flows. The results of this study suggest that these morphologic adjustments have, over time, enabled transport capacity to be reestablished. Despite reduced peak flows, smaller channels enable greater velocities for sediment transport. Therefore, after the adjustment period following impoundment, Yegua Creek has apparently established a new equilibrium in which current channel dimensions are maintained by the sediment transport capacity.

The overall objective of this study was to improve the theory and understanding of the impact of dams on sediment dynamics. Because river sediments form the physical substrate upon which biological organisms function, enhanced understanding of sediment dynamics within dammed rivers is important in sustaining aquatic habitats along these streams. This study provides practical information for aiding dam management and for potential improvements in release practices to help maintain a healthy river system. The sediment downstream of the dam is substantially finer than that found upstream. Suspended sediment concentrations show that sediment is being mobilized downstream of the dam. In addition, shear stresses present are capable of moving the available sediment. Thus, current flows have the potential to mobilize available sediment.

These results are important considering that plans for more dams are in place throughout Texas. If additional dams are planned for the area, a better understanding of sediment dynamics following impoundment is important. In addition, plans for dam removal are increasing. In order to gain a full understanding of what impacts these dams may have, information regarding the effect current dams have on their streams is imperative.

Limitations of Study

The results of this study are considered in the context of several limitations. First, the selection of sample sites was constrained by access. The sites near bridge crossings could also have been impacted by construction materials, which could have affected the characteristics of sediment. Potential bias was avoided to the extent possible by choosing cross sections at reasonable distances from the bridges, although, this could not be completely avoided.

In addition, the samples were taken within a reasonable time frame in an effort to keep discharges similar. The timing of sampling could not be completely controlled, however, due to weather conditions and stream accessibility. In addition, stream access was limited to only those sites with public access, with the exception of one landowner (Landolt, Fig. 18).

Detailed suspended sediment samples at set intervals over a long period of time (like those supplied at various USGS gaging stations) could have aided in this study. However, because suspended sediment samples were not gathered at gaging station 08110000 (Fig. 5), this information was not available. Furthermore, stage and discharge downstream of the dam were not measured by the USGS after 1991. Additional stage and discharge measurements could have given insight into the current flow regime of Yegua Creek.

Transport calculations relied on accurate assessment of Shield's parameter (Eq. 9), which could be over or underestimated based on imbrication and cohesion. In other words, transport calculations determine the capacity for mobilization and not the actual transport taking place under those conditions and sediment sizes. Furthermore, data regarding current stage heights was not available past 1991. This is significant because sediments were sampled in 2007 and could vary from those found at the time stage height was measured.

Finally, an attempt to use aerial photographs to quantitatively determine the presence and size of depositional features was only partly successful due to the inadequate resolution of the 1958 and 1988 photographs and any differences in stage height at the time the aerial photographs were taken. In addition, only photos near the Brazos River, and not the area surrounding Somerville dam were available for the 1958 series.

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Suggestions for Future Research

Future research along Yegua Creek could focus on several issues. Information regarding the influence of tributaries downstream of dams is limited and should be studied further. For example, downstream of Somerville Dam, do tributaries provide a significant amount of sediment to Yegua Creek? What is the difference in sediment characteristics upstream and downstream of tributary confluences? Is sediment supply from tributaries entrained at Yegua Creek's reduced peak flows?

Furthermore, changes in sediment supply and suspended sediment concentration on the Brazos River directly downstream of Yegua Creek could be examined to ascertain potential impacts of Somerville Dam on the Brazos River, and ultimately the Texas coastline. Also, continued monitoring of suspended sediment concentration is necessary to develop a sediment rating curve and determine sediment transport at a range of discharges.

In order to maintain a healthy river system, further investigation of the impact of the effect of riparian vegetation communities on sediment imbrication and entrainment must be examined. With this information, a flow regime that would mimic a pre-dam pattern could be developed. This pattern would limit vegetation encroachment, allowing sediment movement similar to pre dam conditions. To accomplish this, measurement and calculation of imbrication must be carried out. Developing and implementing a pattern similar to the pre-dam flow regime would help maintain a healthy river system and counter the effects of Somerville Dam.

In addition, a sediment budget should be computed to determine the specific effects of Somerville Dam on sediment supply and transport throughout Yegua Creek drainage basin. Similar to Phillips et al. (2004) study on the Trinity River, a sediment budget could clearly determine whether decoupling is taking place. This sediment budget could determine areas of significant alluvial storage and further determine the influence of Somerville Dam on sediment transport to the Brazos River.

Future research must be conducted on the overall impact of dams in the region. For example, what impact has the impoundment of streams providing sediment to the Texas coastline had on sediment availability? With the possibility of the closure of dams in the near future, in addition to the possibility of new impoundments, the effects of dams in the area must be examined. This can help develop practices that manage impoundments and mimic current conditions so healthy river systems are maintained.

Most importantly, further insight must be gained on the interrelationships of the hydrological, morphological, sedimentological and ecological effects of dams. Organism's habitats along the stream are highly dependent on the hydrological regime, morphological and sedimentological characteristics of a stream. Changes in any of these components will affect the type of organisms that inhabit the stream. Significant changes can therefore affect sensitive species that may not have the ability to survive elsewhere. Therefore, careful consideration and evaluation of these impacts is important.. Only then will we know precisely the additive impact and feedbacks impoundments have had on our environment.

Conclusion

In conclusion, the effects of dams on their streams can vary widely. Somerville Dam has had a significant impact on the hydrological, morphological, and vegetation characteristics of Yegua Creek. Accordingly, the sedimentological effects of Somerville Dam are significant. Results from this study add to the growing knowledge of the effects of stream impoundment and serve as a link to future research conducted along Yegua Creek and other streams impacted by dams. These studies will add further knowledge to the effects of dams. They can also help to develop sustainable practices to maintain streams, particularly to the Texas coast.

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APPENDIX A

Table A1 Sediment movement downstream of Somerville Dam. Check marks indicate sediment capable of movement for median (d50) and coarse (d84) sediment size. Movement is indicated by the shear stresses of the flows exceeded the critical shear stresses for movement.

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes (d_{50}) Cross Section						Coarse Sediment Sizes (d_{84}) Cross Section					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
	m	N/m2												
1/4/1967	0.689	0.675	√	√	√	√	√	√	√	√	√	√	√	√
1/5/1967	0.634	0.621	√	√	√	√	√	√	√	√	√	√	√	√
1/6/1967	0.613	0.600	√	√	√	√	√	√	√	√	√	√	√	√
2/8/1967	0.393	0.385	√	√	√	√	√	√	√	√	√	√	√	√
3/16/1967	0.259	0.254	√	√	√	√	√	√	√	√	√	√	√	
4/17/1967	0.335	0.329	√	√	√	√	√	√	√	√	√	√	√	
5/24/1967	0.347	0.341	√	√	√	√	√	√	√	√	√	√	√	
1/26/1968	0.393	0.385	√	√	√	√	√	√	√	√	√	√	√	√
2/12/1968	0.491	0.481	√	√	√	√	√	√	√	√	√	√	√	√
2/20/1968	0.518	0.508	√	√	√	√	√	√	√	√	√	√	√	√
4/4/1968	0.588	0.576	√	√	√	√	√	√	√	√	√	√	√	√
5/13/1968	2.685	2.632	√	√	√	√	√	√	√	√	√	√	√	√
5/17/1968	1.890	1.852	√	√	√	√	√	√	√	√	√	√	√	√
5/31/1968	2.079	2.037	√	√	√	√	√	√	√	√	√	√	√	√
6/18/1968	0.454	0.445	√	√	√	√	√	√	√	√	√	√	√	√
7/5/1968	2.405	2.357	√	√	√	√	√	√	√	√	√	√	√	√
7/11/1968	2.466	2.417	√	√	√	√	√	√	√	√	√	√	√	√
8/14/1968	1.676	1.643	√	√	√	√	√	√	√	√	√	√	√	√
8/15/1968	1.250	1.225	√	√	√	√	√	√	√	√	√	√	√	√
8/16/1968	0.969	0.950	√	√	√	√	√	√	√	√	√	√	√	√
8/17/1968	0.725	0.711	√	√	√	√	√	√	√	√	√	√	√	√
9/23/1968	2.057	2.016	√	√	√	√	√	√	√	√	√	√	√	√

Table A1 continued

Date	Gage Height m	Critical Shear Stress N/m2	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
11/21/1968	0.774	0.759	√	√	√	√	√	√	√	√	√	√	√	√
12/11/1968	2.112	2.070	√	√	√	√	√	√	√	√	√	√	√	√
1/8/1969	0.567	0.556	√	√	√	√	√	√	√	√	√	√	√	√
1/29/1969	0.488	0.478	√	√	√	√	√	√	√	√	√	√	√	√
2/18/1969	2.018	1.977	√	√	√	√	√	√	√	√	√	√	√	√
4/1/1969	2.259	2.213	√	√	√	√	√	√	√	√	√	√	√	√
5/12/1969	2.393	2.345	√	√	√	√	√	√	√	√	√	√	√	√
6/14/1969	0.530	0.520	√	√	√	√	√	√	√	√	√	√	√	√
7/30/1969	0.512	0.502	√	√	√	√	√	√	√	√	√	√	√	√
10/6/1969	0.655	0.642	√	√	√	√	√	√	√	√	√	√	√	√
11/10/1969	0.759	0.744	√	√	√	√	√	√	√	√	√	√	√	√
12/15/1969	0.762	0.747	√	√	√	√	√	√	√	√	√	√	√	√
1/21/1970	0.738	0.723	√	√	√	√	√	√	√	√	√	√	√	√
3/3/1970	1.835	1.798	√	√	√	√	√	√	√	√	√	√	√	√
4/2/1970	2.118	2.076	√	√	√	√	√	√	√	√	√	√	√	√
5/7/1970	0.561	0.550	√	√	√	√	√	√	√	√	√	√	√	√
6/10/1970	2.265	2.219	√	√	√	√	√	√	√	√	√	√	√	√
7/13/1970	0.637	0.624	√	√	√	√	√	√	√	√	√	√	√	√
8/24/1970	0.518	0.508	√	√	√	√	√	√	√	√	√	√	√	√
9/24/1970	0.616	0.603	√	√	√	√	√	√	√	√	√	√	√	√
11/2/1970	0.616	0.603	√	√	√	√	√	√	√	√	√	√	√	√
11/30/1970	0.698	0.684	√	√	√	√	√	√	√	√	√	√	√	√
1/12/1971	0.671	0.657	√	√	√	√	√	√	√	√	√	√	√	√
2/16/1971	0.722	0.708	√	√	√	√	√	√	√	√	√	√	√	√
3/10/1971	0.582	0.571	√	√	√	√	√	√	√	√	√	√	√	√
4/19/1971	0.418	0.409	√	√	√	√	√	√	√	√	√	√	√	√
8/3/1971	0.719	0.705	√	√	√	√	√	√	√	√	√	√	√	√

Table A1 continued

Date	Gage Height (m)	Critical Shear Stress (N/m2)	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
12/1/1971	0.555	0.544	√	√	√	√	√	√	√	√	√	√	√	√
1/10/1972	0.640	0.627	√	√	√	√	√	√	√	√	√	√	√	√
2/9/1972	0.625	0.612	√	√	√	√	√	√	√	√	√	√	√	√
3/15/1972	0.561	0.550	√	√	√	√	√	√	√	√	√	√	√	√
4/7/1972	0.530	0.520	√	√	√	√	√	√	√	√	√	√	√	√
4/19/1972	0.497	0.487	√	√	√	√	√	√	√	√	√	√	√	√
5/18/1972	0.567	0.556	√	√	√	√	√	√	√	√	√	√	√	√
6/26/1972	0.991	0.971	√	√	√	√	√	√	√	√	√	√	√	√
7/31/1972	0.628	0.615	√	√	√	√	√	√	√	√	√	√	√	√
9/8/1972	0.646	0.633	√	√	√	√	√	√	√	√	√	√	√	√
10/4/1972	0.765	0.750	√	√	√	√	√	√	√	√	√	√	√	√
11/13/1972	0.808	0.792	√	√	√	√	√	√	√	√	√	√	√	√
12/18/1972	0.771	0.756	√	√	√	√	√	√	√	√	√	√	√	√
1/26/1973	0.701	0.687	√	√	√	√	√	√	√	√	√	√	√	√
2/20/1973	2.012	1.971	√	√	√	√	√	√	√	√	√	√	√	√
3/2/1973	0.622	0.609	√	√	√	√	√	√	√	√	√	√	√	√
3/29/1973	2.362	2.315	√	√	√	√	√	√	√	√	√	√	√	√
3/30/1973	2.368	2.321	√	√	√	√	√	√	√	√	√	√	√	√
4/9/1973	1.881	1.843	√	√	√	√	√	√	√	√	√	√	√	√
5/7/1973	0.616	0.603	√	√	√	√	√	√	√	√	√	√	√	√
6/14/1973	1.049	1.028	√	√	√	√	√	√	√	√	√	√	√	√
7/17/1973	1.567	1.535	√	√	√	√	√	√	√	√	√	√	√	√
8/22/1973	0.280	0.275	√	√	√	√	√	√	√	√	√	√	√	
10/3/1973	0.305	0.299	√	√	√	√	√	√	√	√	√	√	√	
10/24/1973	2.554	2.503	√	√	√	√	√	√	√	√	√	√	√	√
10/26/1973	2.847	2.790	√	√	√	√	√	√	√	√	√	√	√	√
11/5/1973	2.768	2.712	√	√	√	√	√	√	√	√	√	√	√	√

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
	m	N/m2	Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
11/6/1973	2.627	2.575	√	√	√	√	√	√	√	√	√	√	√	√
11/7/1973	2.481	2.431	√	√	√	√	√	√	√	√	√	√	√	√
11/8/1973	2.280	2.234	√	√	√	√	√	√	√	√	√	√	√	√
11/9/1973	1.935	1.897	√	√	√	√	√	√	√	√	√	√	√	√
12/4/1973	1.862	1.825	√	√	√	√	√	√	√	√	√	√	√	√
1/15/1974	0.402	0.394	√	√	√	√	√	√	√	√	√	√	√	√
2/1/1974	2.621	2.569	√	√	√	√	√	√	√	√	√	√	√	√
2/27/1974	0.320	0.314	√	√	√	√	√	√	√	√	√	√	√	
4/9/1974	0.506	0.496	√	√	√	√	√	√	√	√	√	√	√	√
5/21/1974	0.421	0.412	√	√	√	√	√	√	√	√	√	√	√	√
7/2/1974	0.326	0.320	√	√	√	√	√	√	√	√	√	√	√	
8/13/1974	0.442	0.433	√	√	√	√	√	√	√	√	√	√	√	√
9/24/1974	2.792	2.736	√	√	√	√	√	√	√	√	√	√	√	√
11/5/1974	0.393	0.385	√	√	√	√	√	√	√	√	√	√	√	√
11/14/1974	2.658	2.605	√	√	√	√	√	√	√	√	√	√	√	√
12/17/1974	2.661	2.608	√	√	√	√	√	√	√	√	√	√	√	√
1/28/1975	0.363	0.355	√	√	√	√	√	√	√	√	√	√	√	
3/11/1975	2.097	2.055	√	√	√	√	√	√	√	√	√	√	√	√
4/22/1975	0.439	0.430	√	√	√	√	√	√	√	√	√	√	√	√
6/2/1975	2.563	2.512	√	√	√	√	√	√	√	√	√	√	√	√
6/5/1975	2.707	2.652	√	√	√	√	√	√	√	√	√	√	√	√
7/16/1975	2.103	2.061	√	√	√	√	√	√	√	√	√	√	√	√
8/26/1975	0.262	0.257	√	√	√	√	√	√	√	√	√	√	√	
10/8/1975	0.430	0.421	√	√	√	√	√	√	√	√	√	√	√	√
11/17/1975	0.430	0.421	√	√	√	√	√	√	√	√	√	√	√	√
1/5/1976	0.439	0.430	√	√	√	√	√	√	√	√	√	√	√	√
2/10/1976	0.387	0.379	√	√	√	√	√	√	√	√	√	√	√	

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
	m	N/m2	Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
3/23/1976	0.354	0.346	√	√	√	√	√	√	√	√	√	√	√	
5/4/1976	2.100	2.058	√	√	√	√	√	√	√	√	√	√	√	√
6/15/1976	2.076	2.034	√	√	√	√	√	√	√	√	√	√	√	√
7/14/1976	2.048	2.007	√	√	√	√	√	√	√	√	√	√	√	√
7/23/1976	0.277	0.272	√	√	√	√	√	√	√	√	√	√	√	
9/9/1976	0.424	0.415	√	√	√	√	√	√	√	√	√	√	√	√
10/20/1976	0.472	0.463	√	√	√	√	√	√	√	√	√	√	√	√
12/9/1976	2.100	2.058	√	√	√	√	√	√	√	√	√	√	√	√
1/18/1977	2.118	2.076	√	√	√	√	√	√	√	√	√	√	√	√
1/27/1977	1.890	1.852	√	√	√	√	√	√	√	√	√	√	√	√
2/4/1977	1.183	1.159	√	√	√	√	√	√	√	√	√	√	√	√
2/23/1977	2.128	2.085	√	√	√	√	√	√	√	√	√	√	√	√
4/5/1977	1.588	1.556	√	√	√	√	√	√	√	√	√	√	√	√
4/28/1977	2.685	2.632	√	√	√	√	√	√	√	√	√	√	√	√
5/18/1977	2.103	2.061	√	√	√	√	√	√	√	√	√	√	√	√
6/29/1977	0.354	0.346	√	√	√	√	√	√	√	√	√	√	√	
8/8/1977	0.317	0.311	√	√	√	√	√	√	√	√	√	√	√	
9/19/1977	0.268	0.263	√	√	√	√	√	√	√	√	√	√	√	
10/31/1977	0.290	0.284	√	√	√	√	√	√	√	√	√	√	√	
12/12/1977	0.287	0.281	√	√	√	√	√	√	√	√	√	√	√	
1/23/1978	0.381	0.373	√	√	√	√	√	√	√	√	√	√	√	
3/7/1978	0.451	0.442	√	√	√	√	√	√	√	√	√	√	√	√
4/18/1978	0.500	0.490	√	√	√	√	√	√	√	√	√	√	√	√
5/30/1978	2.018	1.977	√	√	√	√	√	√	√	√	√	√	√	√
7/10/1978	0.914	0.896	√	√	√	√	√	√	√	√	√	√	√	√
8/21/1978	0.226	0.221	√	√	√	√	√	√	√	√	√	√	√	
10/2/1978	0.183	0.179	√	√	√	√	√		√	√		√	√	

Table A1 continued

Date	Gage Height m	Critical Shear Stress N/m2	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
11/15/1978	0.183	0.179	√	√	√	√	√		√	√		√	√	
1/4/1979	0.271	0.266	√	√	√	√	√	√	√	√	√	√	√	
2/1/1979	1.030	1.010	√	√	√	√	√	√	√	√	√	√	√	√
3/20/1979	0.357	0.349	√	√	√	√	√	√	√	√	√	√	√	
4/30/1979	2.109	2.067	√	√	√	√	√	√	√	√	√	√	√	√
6/12/1979	2.505	2.455	√	√	√	√	√	√	√	√	√	√	√	√
7/26/1979	2.042	2.001	√	√	√	√	√	√	√	√	√	√	√	√
9/4/1979	0.402	0.394	√	√	√	√	√	√	√	√	√	√	√	√
10/16/1979	0.418	0.409	√	√	√	√	√	√	√	√	√	√	√	√
11/27/1979	0.427	0.418	√	√	√	√	√	√	√	√	√	√	√	√
1/15/1980	0.408	0.400	√	√	√	√	√	√	√	√	√	√	√	√
2/22/1980	0.570	0.559	√	√	√	√	√	√	√	√	√	√	√	√
4/8/1980	2.134	2.091	√	√	√	√	√	√	√	√	√	√	√	√
5/19/1980	1.747	1.712	√	√	√	√	√	√	√	√	√	√	√	√
6/23/1980	1.859	1.822	√	√	√	√	√	√	√	√	√	√	√	√
8/6/1980	0.732	0.717	√	√	√	√	√	√	√	√	√	√	√	√
9/18/1980	0.311	0.305	√	√	√	√	√	√	√	√	√	√	√	
10/27/1980	0.277	0.272	√	√	√	√	√	√	√	√	√	√	√	
12/11/1980	0.293	0.287	√	√	√	√	√	√	√	√	√	√	√	
1/20/1981	0.457	0.448	√	√	√	√	√	√	√	√	√	√	√	√
3/3/1981	0.293	0.287	√	√	√	√	√	√	√	√	√	√	√	
4/22/1981	1.588	1.556	√	√	√	√	√	√	√	√	√	√	√	√
5/21/1981	0.128	0.125	√	√	√	√	√		√	√			√	
7/9/1981	1.250	1.225	√	√	√	√	√	√	√	√	√	√	√	√
8/13/1981	0.110	0.108	√	√	√	√	√		√	√				
9/23/1981	0.244	0.239	√	√	√	√	√	√	√	√	√	√	√	
11/5/1981	1.984	1.945	√	√	√	√	√	√	√	√	√	√	√	√

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
	m	N/m2												
12/17/1981	0.317	0.311	√	√	√	√	√	√	√	√	√	√	√	
1/28/1982	0.305	0.299	√	√	√	√	√	√	√	√	√	√	√	
3/18/1982	0.265	0.260	√	√	√	√	√	√	√	√	√	√	√	
4/23/1982	0.445	0.436	√	√	√	√	√	√	√	√	√	√	√	√
6/7/1982	2.088	2.046	√	√	√	√	√	√	√	√	√	√	√	√
7/7/1982	0.232	0.227	√	√	√	√	√	√	√	√	√	√	√	
8/19/1982	0.216	0.212	√	√	√	√	√	√	√	√	√	√	√	
9/28/1982	0.326	0.320	√	√	√	√	√	√	√	√	√	√	√	
11/12/1982	0.411	0.403	√	√	√	√	√	√	√	√	√	√	√	√
12/27/1982	0.241	0.236	√	√	√	√	√	√	√	√	√	√	√	
2/2/1983	1.366	1.338	√	√	√	√	√	√	√	√	√	√	√	√
3/16/1983	1.792	1.756	√	√	√	√	√	√	√	√	√	√	√	√
4/26/1983	1.884	1.846	√	√	√	√	√	√	√	√	√	√	√	√
7/8/1983	2.362	2.315	√	√	√	√	√	√	√	√	√	√	√	√
7/20/1983	0.427	0.418	√	√	√	√	√	√	√	√	√	√	√	√
8/31/1983	0.296	0.290	√	√	√	√	√	√	√	√	√	√	√	
10/12/1983	0.341	0.335	√	√	√	√	√	√	√	√	√	√	√	
11/10/1983	0.351	0.344	√	√	√	√	√	√	√	√	√	√	√	
12/12/1983	0.351	0.344	√	√	√	√	√	√	√	√	√	√	√	
2/2/1984	0.314	0.308	√	√	√	√	√	√	√	√	√	√	√	
3/16/1984	0.354	0.346	√	√	√	√	√	√	√	√	√	√	√	
5/1/1984	0.317	0.311	√	√	√	√	√	√	√	√	√	√	√	
5/16/1984	1.875	1.837	√	√	√	√	√	√	√	√	√	√	√	√
6/11/1984	0.265	0.260	√	√	√	√	√	√	√	√	√	√	√	
11/30/1984	0.107	0.105	√	√	√	√	√		√	√				
1/10/1985	2.094	2.052	√	√	√	√	√	√	√	√	√	√	√	√
2/14/1985	0.195	0.191	√	√	√	√	√		√	√		√	√	

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
	m	N/m2												
3/28/1985	2.057	2.016	√	√	√	√	√	√	√	√	√	√	√	√
5/10/1985	1.250	1.225	√	√	√	√	√	√	√	√	√	√	√	√
6/18/1985	0.332	0.326	√	√	√	√	√	√	√	√	√	√	√	
8/2/1985	0.610	0.597	√	√	√	√	√	√	√	√	√	√	√	√
9/10/1985	0.442	0.433	√	√	√	√	√	√	√	√	√	√	√	√
9/26/1985	0.104	0.102	√	√	√	√	√		√	√				
11/6/1985	0.174	0.170	√	√	√	√	√		√	√		√	√	
12/18/1985	2.134	2.091	√	√	√	√	√	√	√	√	√	√	√	√
1/30/1986	1.439	1.410	√	√	√	√	√	√	√	√	√	√	√	√
2/20/1986	1.923	1.885	√	√	√	√	√	√	√	√	√	√	√	√
4/17/1986	0.332	0.326	√	√	√	√	√	√	√	√	√	√	√	
6/4/1986	0.924	0.905	√	√	√	√	√	√	√	√	√	√	√	√
7/24/1986	2.201	2.157	√	√	√	√	√	√	√	√	√	√	√	√
9/11/1986	0.213	0.209	√	√	√	√	√	√	√	√	√	√	√	
10/24/1986	0.524	0.514	√	√	√	√	√	√	√	√	√	√	√	√
12/9/1986	2.006	1.965	√	√	√	√	√	√	√	√	√	√	√	√
1/27/1987	2.289	2.243	√	√	√	√	√	√	√	√	√	√	√	√
3/17/1987	2.256	2.210	√	√	√	√	√	√	√	√	√	√	√	√
5/5/1987	0.296	0.290	√	√	√	√	√	√	√	√	√	√	√	
6/23/1987	2.387	2.339	√	√	√	√	√	√	√	√	√	√	√	√
8/10/1987	2.073	2.031	√	√	√	√	√	√	√	√	√	√	√	√
9/29/1987	0.335	0.329	√	√	√	√	√	√	√	√	√	√	√	
11/17/1987	0.296	0.290	√	√	√	√	√	√	√	√	√	√	√	
12/9/1987	0.323	0.317	√	√	√	√	√	√	√	√	√	√	√	
1/26/1988	0.372	0.364	√	√	√	√	√	√	√	√	√	√	√	
3/16/1988	0.357	0.349	√	√	√	√	√	√	√	√	√	√	√	
5/5/1988	1.079	1.057	√	√	√	√	√	√	√	√	√	√	√	√

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
	m	N/m2	Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
5/10/1988	1.088	1.066	√	√	√	√	√	√	√	√	√	√	√	√
6/23/1988	0.424	0.415	√	√	√	√	√	√	√	√	√	√	√	√
8/8/1988	0.137	0.134	√	√	√	√	√		√	√		√	√	
9/8/1988	1.795	1.759	√	√	√	√	√	√	√	√	√	√	√	√
9/12/1988	0.954	0.935	√	√	√	√	√	√	√	√	√	√	√	√
9/29/1988	0.122	0.119	√	√	√	√	√		√	√				
11/15/1988	0.183	0.179	√	√	√	√	√		√	√		√	√	
1/3/1989	0.219	0.215	√	√	√	√	√	√	√	√	√	√	√	
2/22/1989	0.174	0.170	√	√	√	√	√		√	√		√	√	
4/11/1989	0.113	0.111	√	√	√	√	√		√	√				
6/5/1989	0.119	0.116	√	√	√	√	√		√	√				
6/21/1989	1.844	1.807	√	√	√	√	√	√	√	√	√	√	√	√
7/13/1989	1.000	0.980	√	√	√	√	√	√	√	√	√	√	√	√
7/19/1989	0.162	0.158	√	√	√	√	√		√	√		√	√	
9/7/1989	0.244	0.239	√	√	√	√	√	√	√	√	√	√	√	
10/23/1989	0.320	0.314	√	√	√	√	√	√	√	√	√	√	√	
12/1/1989	0.384	0.376	√	√	√	√	√	√	√	√	√	√	√	
1/18/1990	0.174	0.170	√	√	√	√	√		√	√		√	√	
3/7/1990	0.280	0.275	√	√	√	√	√	√	√	√	√	√	√	
5/2/1990	1.722	1.688	√	√	√	√	√	√	√	√	√	√	√	√
5/10/1990	2.039	1.998	√	√	√	√	√	√	√	√	√	√	√	√
6/18/1990	0.265	0.260	√	√	√	√	√	√	√	√	√	√	√	
8/2/1990	0.259	0.254	√	√	√	√	√	√	√	√	√	√	√	
9/18/1990	0.262	0.257	√	√	√	√	√	√	√	√	√	√	√	
10/30/1990	0.137	0.134	√	√	√	√	√		√	√		√	√	
11/20/1990	0.076	0.075	√	√	√	√	√		√	√				
1/9/1991	0.219	0.215	√	√	√	√	√	√	√	√	√	√	√	

Table A1 continued

Date	Gage Height	Critical Shear Stress	Median Sediment Sizes						Coarse Sediment Sizes					
			Y36US	Y36DS	LA	LB	Y50US	Y50DS	Y36US	Y36DS	LA	LB	Y50US	Y50DS
	m	N/m2												
1/14/1991	1.804	1.768	√	√	√	√	√	√	√	√	√	√	√	√
2/26/1991	2.579	2.527	√	√	√	√	√	√	√	√	√	√	√	√
7/22/1991	0.110	0.108	√	√	√	√	√		√	√				
8/13/1991	0.037	0.036	√	√										
9/10/1991	0.034	0.033	√	√										
1/13/1992	2.682	2.629	√	√	√	√	√	√	√	√	√	√	√	√
3/9/1992	2.966	2.906	√	√	√	√	√	√	√	√	√	√	√	√
4/23/1992	2.630	2.578	√	√	√	√	√	√	√	√	√	√	√	√
6/8/1992	2.316	2.270	√	√	√	√	√	√	√	√	√	√	√	√
7/27/1992	2.524	2.473	√	√	√	√	√	√	√	√	√	√	√	√
9/14/1992	0.085	0.084	√	√	√	√	√		√	√				

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Chin, A., Laurencio, L., and Martinez, A., 2008. The Hydrologic Impacts of Small- and Medium-sized Dams: Examples from Texas. *The Professional Geographer*. (In Press).

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